GUIDANCE FOR INCINERATOR

DESIGN AND OPERATION

VOLUME 1

GENERAL

DECEMBER 1988

⑦ Ontario

GUIDANCE FOR

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Cette publication technique
n'est disponible qu'en anglais.

FOREWARD

This publication is one of a series of documents dealing with incinerator design and operation that have been prepared by the Ontario Ministry of the Environment. The other publications that are or will be available are:

- ° "Guidance for Incinerator Design Operation, Summary and Update."

- ° "Guidance for Incinerator Design and Operation, Volume II, (Biomedical Waste Incinerator)",

- ° "Guidance for Incinerator Design and Operation, Volume III (Crematoria)", and

- ° "Guidance for Incinerator Design and Operation, Volume IV (Cremators for Animal Shelters)".

The mention of trade names or commercial products in the report does not constitute endorsement or recommendation for use.

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Chapter 1
INTRODUCTION

The purpose of this report is to provide guidance to
ensure that incinerators proposed for installation and
operation in the Province will be well designed and comply
with the Ministry's standards and guidelines. This report
is also intended to be used in the evaluation of
incinerator designs and applications for approval by the
Ministry.

The Ontario Ministry of the Environment has initiated a
major program of financial and other support to set up,
operate and promote recycling programs, and has adopted a
cautious approach to waste incineration. Each proposed
incinerator will be assessed on its own merits, and will
be approved only if it is clear that the environment will
be protected.

Chapter 2 discusses applicable legislation and regulations
governing incinerator installations and reviews the prov-
incial approvals process.

Chapter 3 discusses the equipment available for handling
wastes and the layout of that equipment. These front-end
systems determine, to a large degree, the efficiency and
utility of an incinerator. Safety considerations and
recordkeeping are also discussed in this chapter.

Chapters 4, 5, and 6 present design evaluation techniques
for combustion chambers, heat recovery equipment, and
emission control devices, respectively. These techniques
can be used to evaluate a design for effectiveness and
impact on the environment.

A bibliography of pertinent sources is included as Chapter
7.

Appendix A provides a glossary of terms relative to incineration. Appendix B contains supplementary regulatory and approvals information including Ministry Policies related to incineration, addresses of Ministry offices and sample Application forms for Certificates of Approval. Appendix C provides the technical data and procedures required to perform incinerator calculations and presents illustrative examples.

CHAPTER 2
ENVIRONMENTAL LEGISLATION/REGULATIONS

2.1   INTRODUCTION

The complexity of the approval process for the design,
construction, installation, operation, and modification of
an incinerator depends largely on the type of wastes
accepted by the incinerator, where these wastes originate,
and how they are ultimately disposed of. This chapter
presents an overview of the federal, provincial, and muni-
cipal requirements for incinerator applications as well as
a brief discussion of the approvals process. The informa-
tion provided in this chapter is not intended as an
exhaustive review of the legislative and approval require-
ments. In addition, the legislative and administrative
requirements for incinerators, as well as other emission
sources, are currently under review in Ontario. For
example, the Ontario Ministry of the Environment has
initiated the MISA (Municipal and Industrial Strategy for
Abatement) and the CAP (Clean Air Program) initiatives to
virtually eliminate the emission of toxics to the
environment. It is the prime responsibility of the
proponent to determine the specific requirements which
must be met prior to the establishment of an incineration
facility.

2.2   APPLICABLE LEGISLATION

2.2.1   Federal Legislation

Principal federal legislation, regulations, and guidelines
affecting incinerator emissions include the following:

°   Canadian Environmental Protection Act (CEPA)

°   Ambient Air Quality Objectives (No. 1, No. 2, and
     No.3)

°   Packaged Incinerators National Emission Guidelines

°   National Building Code of Canada 1985, Sections
     3.5.2.5; 3.5.2.7; 6.2.6;   9.10.10.7; and 9.10.10.10

The CEPA empowers the Minister of Environment to formulate
ambient air quality objectives and prescribe national
emission standards and guidelines establishing the maximum
quantities of air contaminants that may be emitted into
the air by stationary sources.

The ambient air quality objectives under the CEPA
prescribe the desirable, acceptable, and tolerable ranges
of ambient air quality with respect to sulphur dioxide,
suspended particulate matter, carbon monoxide, ozone, and
nitrogen dioxide.

The Packaged Incinerators National Emission Guidelines
limit the quantities of particulate matter, hydrogen
chloride, and sulphur dioxide which may be emitted into
the ambient air from new installations of packaged incin-
erators.   Packaged incinerator means any furnace used in
the process of burning solid waste whose maximum burning
rate does not exceed 900 kg/h.   These guidelines state
that gases discharged to the atmosphere as a consequence
of the operation of a new installation should not:

a)   exhibit visible emissions which exceed zero opacity;

b)   contain particulate matter in excess of 0.75 g/kg of
     solid waste burned;

c)   contain hydrogen chloride in excess of 100 ppm on a
     dry basis and corrected to 50% excess air; and

d) contain sulphur dioxide in excess of 250 ppm on a dry
    basis and corrected to 50% excess air.

For existing installations, gases discharged to the atmos-
phere should not exhibit visible emissions which exceed
20% opacity.

The National Building Code specifies standards of service
rooms and chimney flues for indoor incinerators. Service
rooms containing an incinerator shall be separated from
the remainder of the building by a fire separation having
a fire-resistance rating of at least 2 hours. However, it
shall not contain other fuel-fired appliances. If the
room is installed with swing-type doors, they shall swing
outward except when the doors open on a corridor or any
room, then they shall swing inward. Every incinerator
shall be served by a chimney flue conforming to the
National Building Code. The design, construction, instal-
lation, and alteration of every indoor incinerator shall
conform to the National Fire Protection Act, 1982 under
"Incinerators, Waste and Linen Handling System and
Equipment."

The above act, objectives, guidelines, and codes should be
consulted for any federal works, undertakings, or business
related to the design, construction, installation, or
alteration of incinerators.

2.2.2   Provincial Legislation

There are three provincial acts that apply to the environ-
mental aspects of establishing an incineration facility in
Ontario, namely:

°   The Environmental Assessment Act (EAA);

°   The Environmental Protection Act (EPA); and

°   The Ontario Water Resources Act (OWRA).

It should be noted that the above Acts and the Regulations
thereunder apply not only to an incineration facility, but
also to any other sources of contaminant emissions.

Prior to the construction of an incineration facility, the
proponent is required to submit applications to the
Ministry of the Environment (MOE) to obtain one or more
Certificates of Approval. Depending on the type and quan-
tity of waste to be incinerated, public hearings may have
to be held as part of the approvals requirements. This
section provides a discussion of the types of Certificate
of Approval required, the various Regulations in the Acts
that apply to such a facility, and an outline of the pro-
cedures used to evaluate an application for a Certificate
of Approval.

The Environmental Protection Act (EPA)

This Act and the two (2) principal Regulations written
under the EPA (Regulations 308 and 309) are intended to
provide for the protection and conservation of the natural
environment.

Part II, Section 8 of the EPA is concerned with air qual-
ity and requires the proponent to submit an application to
the MOE and obtain a Certificate of Approval (Air) from
the Director of the Approvals Branch prior to the con-
struction of an incineration facility, for the methods or
devices or both to be employed to control or prevent the

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emission of any contaminant into any part of the natural
environment.

Regulation 308, the General Air Pollution Regulation,
sets out the maximum allowable point of impingement air
concentration for contaminants that may result from a
point source of emission. The point of impingement refers
to a point where the plume from a source of emission
impinges on a critical or sensitive receptor such as a
building, structure, or the ground. Regulation 308 also
includes the method of calculation to be used in arriving
at point of impingement concentrations. Point of impinge-
ment standards have been established for 100 contaminants
(e.g. suspended particulate, SO_2, CO, NO_x, and HCl).
Moreover, tentative standards, guidelines, and/or provis-
ional guidelines have also been provided for more than 100
other compounds (e.g. PCBs, chlorinated dibenzodioxins,
and furans). Copies of the current list of tentative
standards, guidelines, and provisional guidelines are
available from the Air Resources Branch, 880 Bay Street,
Toronto M5S 1Z8, Telephone (416) 965-5776.

Regulation 308 also has requirements regarding opacity;
also abnormal operation; incinerator capacity; and an
incinerator organic matter emission limit of 100 ppm
expressed as methane.

Part V of the EPA deals with waste management and Section
27 stipulates that no person shall use, operate, estab-
lish, alter, enlarge, or extend a waste management system
or a waste disposal site unless a Certificate of Approval
or a provisional Certificate of Approval has been issued
by the Director and accepted in accordance with any condi-
tions set out in such Certificate.

Policies 01-01 and 01-03 (see Appendix B) apply to new refuse incinerators that burn one or a combination of domestic, commercial, or non hazardous solid industrial wastes. Policy 01-01 "Combustion in Incinerators" establishes design and operating guidelines, and policy 01-03 "Air Pollution Control on Incinerators" requires the installation of state-of-the-art air pollution controls on all new refuse incinerators. An interim guideline prepared for discussion purposes in interpreting this policy establishes emission limits for particulate matter and hydrogen chloride for these incinerators.

The General Air Pollution Regulation prohibits the operation of existing apartment incinerators as of May 31, 1989.

The Ontario Water Resources Act (OWRA)

The OWRA was enacted to ensure effective management of Ontario's water resources and to maintain water quality at a level that is satisfactory for aquatic life and recreational use. Section 24 of the OWRA is concerned with water quality and the discharge of wastewaters into a watercourse (e.g. lake, river, stream). This Section requires the submission of plans, specifications, and an engineering report of the works to be undertaken, and the location of the effluent discharge together with such information as the Ministry may require for a technical review prior to the issuance of the Certificate of Approval.

Effluent discharge requirements are established on a case-by-case basis taking into account the characteristics of the receiving water body and consistent with MOE's water management goals, policies, objectives, and implementation

procedures. If the effluent is discharged to a sanitary
sewer, compliance with the local sewer bylaw as well as
concurrence from the municipality involved are required;
however, approval from the Ministry for the discharge is
not necessary. The municipality may approach the Ministry
for advice regarding the acceptability of discharge into
the sanitary sewer.

The Environmental Assessment Act (EAA)

The Environmental Assessment Act is intended to promote
good planning, informed decision-making, and ultimately
the protection of the environment by requiring proponents
to put forward for approval undertakings which have an
acceptable balance of advantages and disadvantages. This
involves considering a broad range of alternatives, look-
ing at the net environmental effects as well as the advan-
tages and disadvantages to the environment of each alter-
native, and then narrowing down the range to the preferred
alternative. In approving the undertaking (project), the
advantages have to be seen to outweigh the disadvantages
in achieving the purpose of the EAA.

A project which is subject to the EAA may not proceed
until the Minister has accepted the EA and the undertaking
has been approved. Approvals, licences, grants, loans,
orguarantees under other legislation and regulations
cannot be given prior to approval under the EAA.

The hearings and approvals process under the Environmental
Assessment Act is outlined in Figure 2-1. Under the EAA,
a hearing is optional at the discretion of the Minister.
Should a hearing be required, it will be conducted by
either the Environmental Assessment Board or the Consoli-
dated Hearings Board, depending upon the nature of the
approvals required.

PRE-SUBMISSION CONSULTATION

EA SUBMISSION AND REVIEW

PUBLIC REVIEW PERIOD

NOTICE TO HEARINGS REGISTRAR FOR CHA

EAA HEARING NOT REQUIRED

EAA HEARING REQUIRED

ESTABLISHMENT OF JOINT BOARD (JB)

EA DOCUMENT ACCEPTED OR AMENDED AND ACCEPTED

HEARING BEFORE THE JB

DECISION ON APPROVAL OF UNDERTAKING BY MINISTER WITH CABINET APPROVAL

DECISION ON ACCEPTANCE, APPROVAL AS REQUIRED

CABINET MAY VARY DECISION OR REQUIRE NEW HEARING

EPA CERTIFICATE OF APPROVAL

NOTE :

- The CHA Board decision can be appealed to Cabinet
- The Director's decision on the Certificate of Approval may be appealed to the Environmental Appeal Board

EAA - Environmental Assessment Act
EPA - Environmental Protection Act
CHA - Consolidated Hearing Act

⬡ - OPTIONAL
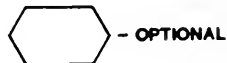
Figure 2-1

SIMPLIFIED REPRESENTATION OF THE HEARINGS AND APPROVALS PROCESS FOR WASTE MANAGEMENT UNDERTAKINGS WHEN AN ENVIRONMENTAL ASSESSMENT IS REQUIRED

Once approval has been granted by either the Minister or the Board, the proponent can proceed with specific EPA approvals.

The definition of environment in the EAA (clause 1(c)) provides the scope of inquiry required for the evaluation of each alternative leading to the selection of the preferred alternative. Environment includes social, cultural, economic, natural, and technical components.

On March 13, 1987, the Ontario Government indicated that public and private waste incineration facilities will be subject to the same legislative and approvals requirements.

The following facilities are subject to the Environmental Assessment Act:

° hazardous waste incinerators;

° liquid industrial waste incinerators; and

° municipal and/or non-hazardous industrial waste incinerators which burn 100 tonnes or more per day.

The EA Act requires a reasonable planning effort, taking into consideration the proponents' nature, aims, resources and capabilities.

If a project is subject to the EAA, the proponent must submit an Environmental Assessment document (EA) to the Minister of the Environment for acceptance and approval. Upon receipt of the EA, the Ministry circulates the document to all appropriate government agencies (including the

Medical Officer of Health, Conservation Authority, and Environment Canada) for their comments and concerns. The Ministry prepares a government review which is meant to address the quality of the EA by providing a balanced evaluation. After the review is published, a public notice is given to provide all interested parties and the public the opportunity to comment on the EA and the review.

The EAA specifies the minimum requirements of the content of an EA that is submitted (subsection 5(3) of the Act) and this includes the evaluation of the net environmental effects and advantages and disadvantages to the environment of each alternative to the undertaking and alternative method of carrying out the undertaking.

Public participation and consultation with members of the government review team are key ingredients in the planning of a waste facility. This consultation is discussed in more detail in the Ministry's Guidelines for Pre-Submission Consultation Associated with the Environmental Assessment Act.

Further information on the EA process and requirements is available from the Ministry in the "General Guidelines for the Preparation of Environmental Assessments."

2.2.3   Municipal Requirements

Proponents wishing to install and operate an incineration facility should contact the municipality in which the incinerator is located. Generally, Ontario municipalities do not have specific bylaws regulating the design and operation of incinerators.

Most municipalities require plans and specifications to comply with relevant sections of the National Building Code, as outlined in Appendix B.

In addition, the proponent should consult the municipality on bylaw requirements relating to noise, hours of operation, zoning, and odour. In the event that wastewater is to be discharged to a municipal sewer as a result of the incinerator operation, the concurrence of the municipality is required and the proponent should consult the local sewer bylaw requirements for wastewater discharge.

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2.3   APPROVALS PROCESS

2.3.1   Procedures Used to Evaluate Applications for Certificates of Approval under the EPA and OWRA

Upon receipt of the applications and the supporting information, including plans, specifications, and design details, a technical review of all units of the systems for the collection, treatment, and control of emission of contaminants will be carried out in order to determine if the proposed facility complies with the Ministry's requirements. A simplified flow chart for approvals under the EPA and the OWRA is illustrated in Figure 2-2.

Air Emissions

For approvals under Section 8 of the Environmental Protection Act, dispersion calculations are carried out to ascertain if the emissions from the proposed facility would comply with the point of impingement concentration standards (Regulation 308) and/or guidelines at the critical receptors. A heat and material balance calculation is
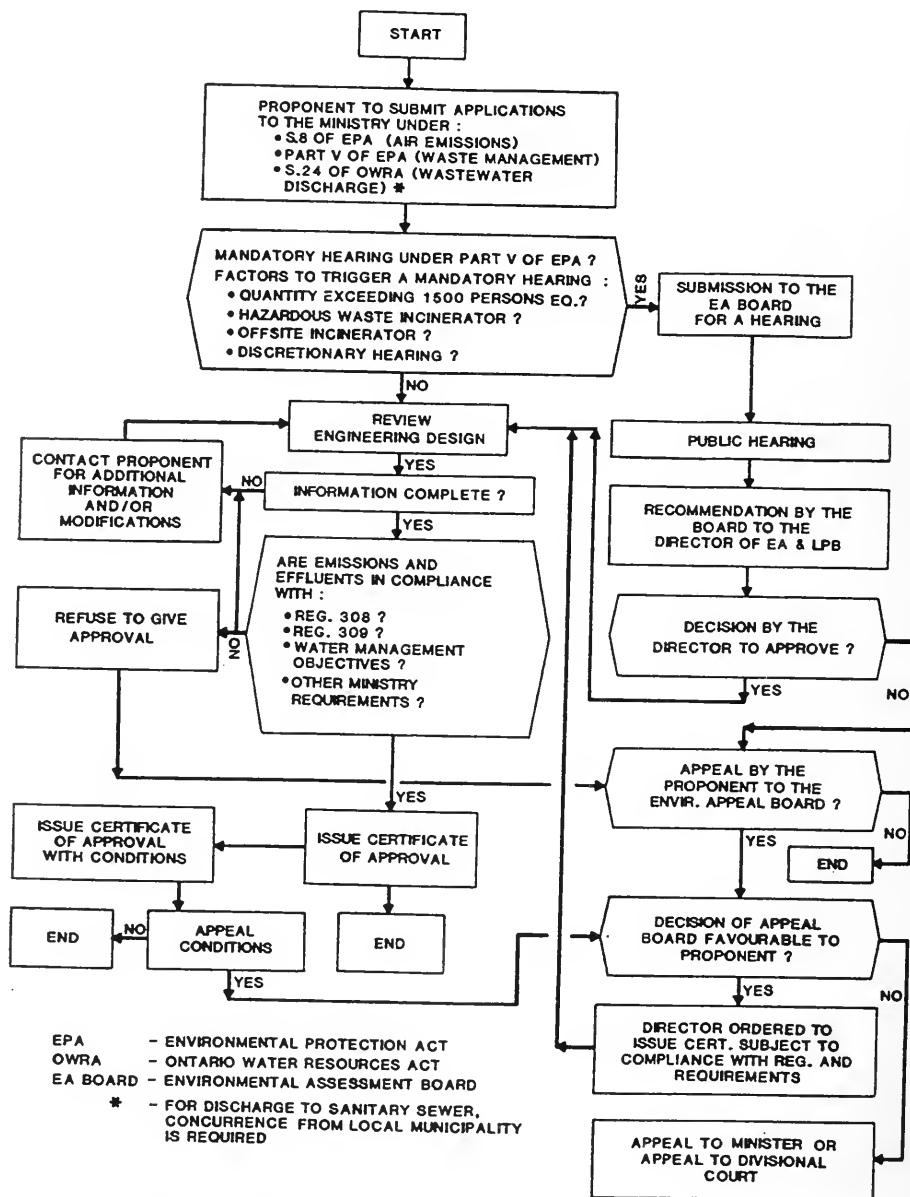
Figure 2-2

SIMPLIFIED REGULATORY APPROVALS PROCESS UNDER THE ENVIRONMENTAL PROTECTION AND THE ONTARIO WATER RESOURCES ACTS

also performed to determine if the facility would meet the specified temperature and retention time requirements.

The point of impingement concentrations are calculated in accordance with the Appendix of Regulation 308. The Regulation provides three formulae to be used for the dispersion calculation and the choice of a proper dispersion model is mainly based on the height of the stack relative to that of the building on which the source of emission is located and the proximity to the critical receptors.

Wastewater Discharge

If the wastewater is to be discharged to a receiving stream or natural watercourse, the quality of the effluent should comply with the requirements set out in the Ministry "Water Management, Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment, November, 1978, revised May, 1984." Effluent requirements are established on a case-by-case basis, and take into consideration the characteristics of the receiving water body or "mixing zone". Mixing zone is defined as an area of water contiguous to a point source where the water quality does not comply with the Provincial Water Quality Objectives. The size of the mixing zone is determined on a case-by-case basis and is to be minimized to the greatest possible degree and under no circumstances is the mixing zone to be used as an alternative to treatment.

Ash Disposal

Ashes produced by all incinerators should be tested by the leachate extraction procedure to determine how they should be managed.

CHAPTER 3
GENERAL CRITERIA

3.1   WASTE RECEIPT AND HANDLING

3.1.1   Waste Receipt

3.1.1.1 Municipal Solid Waste

Weighing Facilities. Weighing of incoming municipal waste
is necessary to determine the quantity of wastes received
and to help regulate the operation of the facility.

There are three types of scales in general use for weigh-
ing the wastes: beam weight, load cell, and combination
mechanical/electronics scales.

In selecting a scale, a 45-tonne (50-ton) capacity is
usually adequate. Platforms 3 m (10 ft) wide by 10 m
(33 ft) long are sufficient for weighing packer trucks.
However, if tractor-trailer transfer vehicles will be
bringing wastes to the facility, a 15-m (50-ft) platform
length is required. Adequate provisions should be made
for signal lights, curbing and drainage, alarms, and auto-
mated recording devices.

Information that should be recorded when trucks are
weighed includes:

°   Date and time

°   Vehicle identification

°   Tare weight

°   Gross weight

°   Net weight (gross weight less tare)

The scale system must be adequate to handle the maximum
expected number of vehicles without excessive delays or
backups. With an automated system, approximately one
truck can be weighed each minute, or 60 trucks per hour
per scale.

3.1.1.2   Industrial Waste

<u>Waste Receiving Area</u>. The type and nature of industrial
waste received at an incinerator facility will dictate the
design and equipment within the waste receiving area. The
physical types of hazardous waste that may be received
are:

°   Bulk liquid

°   Containerized materials (liquid and solids)

°   Dry solid materials

°   Wet solid materials (pumpable and non-pumpable)

The types of receiving equipment for unloading can be
divided into three general areas:

°   Pumpable liquid transfer

°   Container transfer

° Bulk solids transfer

Liquids Unloading. Liquids can arrive in bulk in tank cars or tank trucks by either truck or rail. Standard rail tank cars vary in capacity from 23 to 100 m³ (5,062 to 22,000 I gallons), and tank trucks carry up to 38 m³ (8,400 I gallons).

The site should be arranged, through the use of either natural grade or diversionary dikes or drains, so that escaping liquid will flow to a safe location. When possible, 15 m (50 ft) or more of clear space should be provided between unloading stations and buildings.

Pumpable materials can be transferred through piping by pump, gravity flow, or compressed-gas displacement. Pumping systems are most commonly used and have an inherent safety advantage in that they can be designed so that the flow of liquid ceases when the pump is stopped.

The safest method of unloading a tank car or truck is through the top by means of a pump with extended suction. Tank trucks, however, are usually unloaded from the bottom by gravity or by pumps mounted on the vehicle. Positive-displacement pumps are the preferred method for transferring liquid wastes. Centrifugal pumps may be suitable for service where the vapour pressure of the waste is not exceeded by the pump suction.

Spill and Runoff Containment. Drainage from the unloading area should be collected or diverted to permit recovery or, at least, proper disposal of any spills or runoff. The basic objective of containment is to prevent the discharge of hazardous materials to waterways, sewer systems, or groundwaters.

Container Unloading. Containerized hazardous waste is
most likely to arrive for unloading via rail boxcar or
truck semitrailer. A 200-l (44-I gallon) drum is the most
popular form of container; a boxcar can carry 360 such
drums per carload.

Bulk Solids Unloading. Bulk solids for incineration
generally arrive for unloading in hopper cars--both truck
and rail. If the materials are hazardous, the hopper cars
must be the covered type, typically with bottom unloading
ports.

Mechanical Conveyors. When a discharge pit is used for
unloading, the material is conveyed to storage via one or
more of three methods:

°   Screw conveyor - a long pitch, steel helix flight
    mounted on a shaft supported by bearings within a
    U-shaped trough

°   Belt conveyor - an endless neoprene-type belt moving
    horizontally or on an incline on a series of idlers

°   Bucket elevator - a relatively simple unit for making
    vertical lifts. They should be totally enclosed to
    reduce fugitive dust emissions.

Pneumatic Conveyors. Pneumatic conveyors are commonly
used to transfer dry granular or powdered materials, both
vertically and horizontally, to plant areas that are hard
to reach with mechanical conveyors. The properties of a
material determine whether or not it can be successfully
conveyed pneumatically. The material must pass through
piping and auxiliary equipment without clogging, degrada-
tion, or segregation; it should not readily absorb mois-
ture; and it must be readily disengaged from the conveying

air. Materials from fine powders through 6-mm (1/4-inch)
pellets can be handled.

3.1.2   Waste Storage

3.1.2.1 Municipal Solid Waste Storage

Storage Facilities.   There are four general types of
receiving/storage facilities for as-received refuse:

o   Pit and Crane. This is commonly used in mass burning
     incineration systems. It has the advantage of ease of
     refuse handling and requires relatively little area.
     Its disadvantages include high construction cost, the
     need for a crane (which represents relatively high
     maintenance costs), difficulty in cleaning the pit,
     and difficulty in controlling fires in the pit.
     Refuse pits are normally sized for 3- or 4-day refuse
     storage.

o   Tipping Floor. This is often used where front end
     processing is intended. Its advantages include the
     ability to clean the floor regularly and the ability
     to pre-sort the refuse to eliminate unprocessable and
     hazardous items. Also, refuse handling is accomplish-
     ed with proven, reliable equipment (wheeled and skid
     loaders). Its disadvantages include the need for a
     large, unobstructed floor space and the large floor
     area required to provide more than a few hours of
     storage.

o   Depressed Tipping Floor. This variation on the tip-
     ping floor concept uses an elevated area from which
     trucks dump onto a depressed flat floor; whee tracked
     vehicles manipulate the refuse in the depressed area.
     Advantages include separatio the vehicle unloading and

refuse handling functions, increased storage capacity,
refuse pre-sorting, and the possibility of refuse
compaction by the tracked vehicles.

°   Live Bottom. This type of storage facility consists
    of a large pit with either apron conveyors or hydraul-
    ic ram conveyors at its bottom for transfer and charg-
    ing of refuse. Advantages include separation of
    unloading and refuse handling, automation of refuse
    handling, and greater refuse storage capacity in
    reduced space. Disadvantages include high construc-
    tion cost and difficulty in separating unprocessable
    and/or hazardous items. Another problem with this
    system is that refuse may not feed itself onto the
    conveyor but may bridge above the conveyor surface
    creating severe operating problems.

3.1.2.2   Industrial Waste Storage

<u>Waste Storage Area</u>. Wastes received for incineration at a
disposal facility are either incinerated directly (in some
cases via pumping directly from the tank truck) or stored
until they can be handled more conveniently. At some
plants, waste blending occurs prior to storage. A waste
sampling station must be included in the facility.
Sampling of waste must be made prior to incineration.
Analysis of samples can be onsite or at an offsite labora-
tory.

A hazardous waste storage area is normally designed to
address three problem areas:

°   Segregation of incompatible corrosive and reactive
    waste types

°   Fire hazards due to flammable liquids and solids

°   Toxic hazards to prevent human exposure during stor-
age, transfer, and spill possibilities

3.1.2.3 Types of Storage

<u>Liquid Storage</u>. Liquid waste storage normally includes
temporary holding tanks, batching tanks, main storage
tanks, and transfer pumps. Holding tanks provide initial
storage of wastes prior to final disposition of the
material. Other tanks can store specific waste categories
that have been analyzed and are ready for batching or
incineration. Batching tanks are normally used to prepare
an 8-hour shift of waste feed for the incinerator. Also,
tanks may be needed to store supplemental fuel for incine-
rator firing.

Dikes must be provided around liquid waste storage tanks
to contain any spills. A sump should be located within
the diked area to collect spills and from which waste can
be pumped. Another consideration in the design of a stor-
age tank installation is control of release of volatile
organic compounds from tank vents. Where storage tanks
feed an incinerator, the vent can be directed to the
incinerator for organic gas destruction. Any volatile
organic discharge to the atmosphere, including tank
breather vents, is subject to impingement point require-
ments of MOE regulation (see Chapter 2).

Installation and maintenance of aboveground tanks are less
troublesome than for underground tanks. With underground
storage, the functions of gauging, pumping, and leak
detection become more difficult. Storage of hazardous
wastes and liquids in underground tanks is discouraged

because of the possibility of undetected leakage, whereas leakage can be visually determined in aboveground tanks.

Bulk Solids Storage. Solid hazardous waste materials that present a toxicity problem to plant personnel are normally stored in totally enclosed storage, such as single-outlet bins, multiple-outlet silos, and portable bins. These enclosures protect the material from exposure to the elements; they guard against dangers represented by possible explosive, flammable, ignitable, or corrosive properties of the waste material.

Industrial wastes are occasionally stored in piles (which are generally small). Many piles are in buildings or are maintained outside under cover on concrete pads. They are most frequently used to accumulate waste composed of a single, dry material.

Container Storage. Hazardous materials for incineration may arrive in small container form (e.g., 200-1/44-I gallon drums). The containers can be stored as received until used, provided they are in good condition and are not leaking.

The containers should be stored in a covered area off the ground in a manner that will preclude damage, weathering, and subsequent leakage. Storage pads of concrete or other relatively impervious materials should be used as a base to prevent leaching or percolation to groundwater.

3.1.3   Handling and Conveyor Systems

The following materials handling equipment is commonly used at incineration facilities.

Apron Conveyors. Apron conveyors consist of a series of jointed steel pans connected and driven by chains. They are used to convey unprocessed solid waste, generally as infeed to a primary shredder or trommel.

One type of apron conveyor that has proven successful in handling solid waste is the double-beaded, outboard roller type. If the feeding conveyor is wider than the subsequent (downstream) conveyor or equipment inlet port, "funneling" is very likely to occur, causing bridging and blockages. In addition, changes in direction should not be attempted when conveying unshredded solid waste.

Belt Conveyors. Belt conveyors are widely used to convey solid waste and various waste components after shredding. One exception is the shredder discharge conveyor itself; because material exits the shredder at a relatively high temperature (up to 100°C) and/or velocity, metal apron or vibrating conveyors are advisable.

Pneumatic Conveyors. Pneumatic conveying systems are available for the transport of the light fraction of shredded solid waste (RDF). These systems usually convey the material from an air classifier to storage. They consist of a blower, connecting ductwork, a cyclone for separating the light fraction from the conveying air, a fabric filter for final control, and a rotary airlock to discharge the light fraction from the cyclone. Pneumatic conveyors can also be used to move shredded material from storage to an incinerator.

Screw Conveyors. Screw conveyors are widely used to move granular solids and sludge waste. They can be run at an incline, although their maximum capacity rating is in the horizontal position. Screw conveyors longer than 3.6 m (12 ft) normally require intermediate support. If inter-

nal bearings are used, they should be positioned within
the screw conveyor to minimize contact with the waste
stream. Supporting an internal bearing from above is one
such method. Likewise, end bearings should be mounted
outboard of the conveyor to prevent contact with the waste
stream.

3.1.4   Solid Waste Preparation

Trommel Screens. A trommel is a rotating perforated screen
through which material is fed so that it can be classified
by particle size. The inside face of the screen may have
protruding knives or cutters that facilitate the breaking
of plastic bags.

Shredding. Size reduction of incoming solid wastes is
desirable to ease the handling of the wastes and to
increase the burning efficiency of the incinerator. When
wastes are received at a facility, they range in size from
bulky, oversized materials to small particles. Shredding
reduces the volume of material being handled, promotes
more efficient handling of the wastes for other processes,
and prepares the waste for air classification. Size
reduction also increases the surface area of the wastes
and promotes more efficient burning.

There are a number of different types of shredders commer-
cially available. A rotary shear type shredder is a dual
shaft unit utilizing counter-rotating cutters to tear and
shear the waste. Flail mills are shredders which utilize
a single rotor with various types of impactors (blades,
chains, etc.) attached to the rotor to beat, cut, or
thrash the waste.

Hammermills, both the horizontal shaft and vertical shaft
types, are the most common equipment used for size reduc-

tion of municipal solid wastes. The horizontal hammermill has bottom grates and a horizontal rotating shaft. The grates control the discharge particle size.

With a vertical shaft hammermill, the input is fed at the top, and the rotating shaft is vertical. Size reduction is controlled by the spacing between the side walls and hammer on the rotary shaft. The mill is tapered so that the bottom is smaller than the top.

Both types of hammermills operate at approximately the same power efficiency; however, there are differences between the vertical and horizontal mill, as noted in Table 3-1.

Table 3-1
Comparison of Horizontal and
Vertical Shaft Hammermills

Parameter	Horizontal Shaft	Vertical Shaft
Particle size control	Positive control; all material processed until small enough to pass grates	Not positive control; particle size controlled by feed size
Shredding of difficult materials	Subject to damage from oversized and difficult material; pre-sorting and/or top screens desirable	Less subject to damage; difficult items pass through machine; presorting not necessary
Wear rates	Hammer wear rates may be higher	Particle size gradually reduced so that wear on hammers is more evenly distributed
Motor Drive	Most manufacturers recommend direct drive	Most manufacturers recommend a gear or belt drive

The design of a shredder installation should include provisions for handling and storage of the wastes. Input is usually fed to the shredders by a conveyor and the output is brought to the next processing step by conveyor.

In addition to the feed and discharge systems, provisions for dust, explosion, and fire control are necessary at shredder installations. Water spray systems have been used successfully to control dust and fires at several installations; this method has the disadvantage of increasing refuse moisture content, which is counterproductive for incineration.

Another method to control dust and limit explosions is to continually exhaust the shredder housing with a pneumatic system. Such a system conveys the collected dust to a central point for storage and disposal.

Proprietary explosion suppression systems, such as the "Fenwal" system, flood the shredder housing with an inert gas in response to an extremely fast-acting pressure sensor that can react to certain types of explosions before pressures reach destructive levels.

Air Classification. Air classifiers, such as the one shown in Figure 3-1, are used to separate components in the solid waste stream. Shredded solid waste is separated into a "light" fraction (consisting primarily of paper, plastic, and other light organic material) and a "heavy" fraction (consisting of heavier organic and inorganic material).

Air classifiers generally operate by allowing the waste stream to fall through a rising current of air. Light particles with large surface areas are lifted by the air current; heavy and/or dense particles fall.
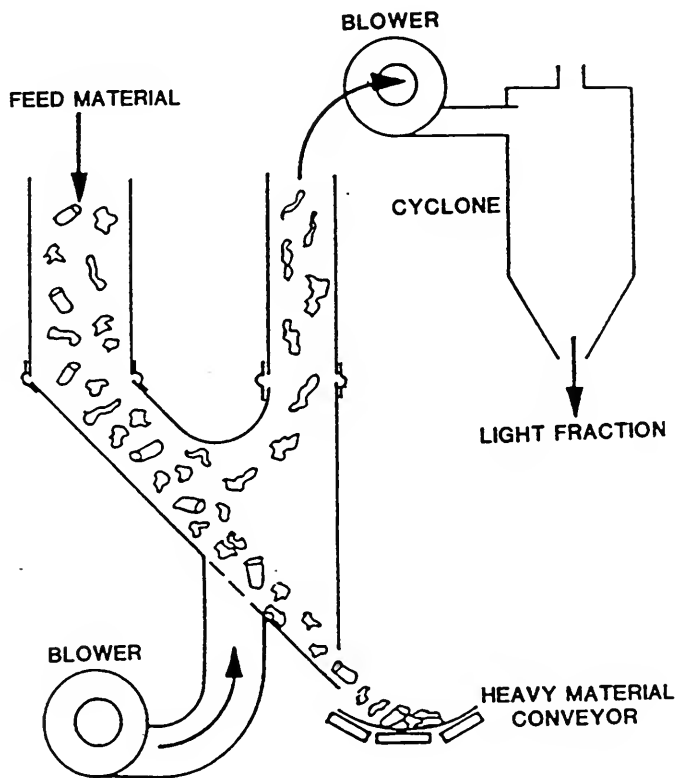
Figure 3-1
AIR CLASSIFIER
(Triple/s)

A reasonable performance level for an air classifier is 85% recovery of light fraction with about 5% to 10% carry-over of heavy organics and inorganics.

3.2   SYSTEM SAFETY CONSIDERATIONS

3.2.1   Personnel Safety

The health and safety of the public and of plant employees should be considered of prime importance in any industrial installation design or operation. Equipment should be provided for worker protection, and procedures for worker protection should be developed.

3.2.2   Safety in Handling and Storage

3.2.2.1 Chemical-Spill Handling Plan

A chemical-spill handling plan should be provided for industrial incinerator installations. It should include:

° Monitoring requirements for possible spills of material

° Description of hazards associated with material that may be spilled

° Designation of the chain of command during a spill incident

° Specifications of equipment available for containment

° Disposition alternatives in response to a spill

3.2.2.2 Unloading and Transfer Safety and Emergency Provisions

Hazardous fluid unloading and transfer operations offer a high likelihood of accident, i.e., fire, spills, or worker exposure. Technical bulletins of the Chemical Manufacturers Association (CMA) and the American Petroleum Institute (API) provide guidance for the safe unloading of tank cars and tank trucks.

3.2.2.3 Storage Area Safety Provisions

Some provisions to protect personnel and the immediate environment from fire hazards and material spills that apply to the storage of large quantities of flammable liquids include:

°   Provision of remotely operated valves to minimize flow of flammables

°   Combustible gas monitors in the storage area

°   Combustible gas monitors that automatically actuate a deluge system or safely shut down the system

°   Drainage and collection ponds (equalization basins) to carry away liquid spills resulting from a fire incident

For the storage of drums, many safety precautions can be instituted for the protection of the operators who open and inspect drums prior to incineration. Safety features include:

- Explosion-proof electrical equipment

- Dry chemical and CO_2 fire extinguishers

- Special safety fork trucks with nonsparking forks

- Air-operated pumps

- Nonsparking tools

- Safety showers and eyewashes

- Safety glasses and face shields

- A general ventilation system with a moderate ventilation rate (minimum of three air volume changes per hour) and a high ventilation rate (minimum 12 air volume changes per hour) in the drum pumping room or area

For storage of bulk solids, evidence of spontaneous heating should be closely monitored. Heat-sensitive devices should be installed in silos and bins; they should be connected to a continuous temperature recorder at a central control board and arranged to sound an alarm if unsafe temperatures are generated.

3.2.2.4 Pump and Piping Safety Provisions

Hazardous and flammable-liquid pumping and piping systems should be equipped with emergency shutoffs to stop the flow of liquid in the event of fire or accidental escape of liquid or vapour.

3.2.3 Safety Combustion Control

Three supplemental fuels are in common use at incinerator facilities:

° Fuel oil (#2 grade normally used)--39 000 kJ/l (167,000 Btu/I gallon)

° Natural gas--37 000 kJ/m³ (1,000 Btu/ft³)

° Digester gas--15 000 to 22 000 kJ/m³ (400 to 600 Btu/ft³)

All new construction invariably uses automatic combustion control. As listed in Table 3-2, combustion control starts with the generation of a pilot flame, the proof of the pilot, the firing of the main fuel gun, and the proof of main flame.

Prior to any firing, a purge is initiated to preclude hide-out of combustible mixtures within the furnace that could cause explosion. Purging requires the placement of air-moving equipment (fans) in operation to produce an air wash, or purge, of the furnace for a minimum period of time.

The pilot is normally gas, which is electric spark ignited. It may be on only for that period of time required to light the main burner and prove combustion.

3.2.4 Noise Control

In planning, construction, and operation of an incineration facility the proponent should comply with the pro-

Table 3-2
Combustion Control Requirements for Different Burner Systems

	Underwriters Laboratories 296 (Oil)	Underwriters Laboratories 795 (Gas)	Factory Mutual Auto Lighted Boilers	Industrial Risk Insurers Automatic Single Burner	National Fire Protection Association 85
Scope	Over 400 000 kJ/h	Over 400 000 kJ/h	3.5×10^6 kJ/h Oil 1.8×10^6 kJ/h Gas	Over 400 000 kJ/h	Over 12.5×10^6 kJ/h
Prepurge	No Mention	° 4 air changes at 1/3 air flow minimum or ° 30 s @ highfire air flow rate ° 90 s @ 1/3 highfire air flow rate ° Atmospheric 90 s without automatic shutters; no prepurge required	° 4 air changes @ 50% average air flow superised ° Automatic dampers which close during down time on natural draft boiler must be opened 90 s prior to each start	4 air changes @ 60% min. air flow supervised	8 air changes reaching not less than 70% air flow supervised
Pilot Proving	° Required over 75.7 L/h starting rate ° 15 s	° Under 2.5×10^5 kJ/h – 15 s ° Over 2.5×10^6 kJ/h – 10 s	10 s	10 s max.	10 s
Main Flame Trial for Ignition (Oil)	° Spark or unproved pilot 11.4 L/h max. 90S 11.4 to 26.5 L/h –30S 26.5 to 75.7 L/h –15S ° Over 11.4 L/h with proved pilot Distillate –10S Residual –15S	Not Applicable	° No. 2 & 4 oil – 10 s ° No. 5 & 6 oil – 15 s	° No. 2 & 4 oils – 10 s ° No. 5 & 6 oils – 15 s * UL timings take precedence	° No. 2 & 4 oils – 10 s ° No. 5 & 6 oils – 15 s
Main Flame Trial for Ignition (Gas)	Not Applicable	° Under 2.5×10^6 kJ/h – 15 s ° Over 2.5×10^6 kJ/h – 10 s	10 s	15 s (published) UL takes precedence	10 s
Flame Failure Response Time	4 s max.	4 s max.	4 s max.	4 s max.	4 s max.
Interlocks Required	Shutdown on loss of atomizing means	Over 2.5×10^6 kJ/h non-recycling high and low gas pressure switches	° Over 12.5×10^6 kJ/h prove fuel valve closed prior and during purge ° Low fire start ° Low oil temp. NON-RECYCLING ° High and low gas pressure ° Min. air flow ° Atomizing medium	° High and low oil temp. ° Low fire start NON-RECYCLING ° Supervised ° Atomizing medium ° High and low gas pressure ° Min. combustion air pressure ° Rotary burner power outage to motor ° Low oil pressure	° Low fire start ° Manual start from cold start ° Prove safety shutoff valve closed NON-RECYCLING ° Loss of combustion control system activating energy ° Low oil temp. and pressure ° Atomizing medium ° Minimum air flow

* Underwriters Laboratories

visions of the "Model Municipal Noise Control By-Law, Aug. 1978", Technical Publication NPC-133, guidelines on information required from the assessment of planned stationary sources of sound, Technical Publication NPC-105, stationary sources, and Technical Publication 132, guidelines for noise control in rural areas.

Noises generated within an incineration facility are generally those resulting from the movement of air or gas. Fans and blowers will create the greatest noise levels, and of secondary concern is the noise generated by passage through ducts, flues, and nozzles.

Noise exposure to operators, other personnel within the facility limits, and the general environment must be considered as part of the facility design.

Where a worker is likely to be exposed to a sound (noise) level of 90 decibels or greater, measures shall be taken to reduce the sound level below 90 decibels. If such measures are not practical, the duration of exposure shall not exceed that indicated in Column 2 of Table 3-3 or the worker shall wear hearing protection. A worker shall always wear hearing protection when the sound level is or is expected to be 115 decibels or greater.

Clearly visible warning signs shall be posted to the approaches to an area where the sound level is more than 90 decibels as indicated in the Occupational Health and Safety Act and Regulations for Industrial Establishments, Chapter 321 of the Revised Statutes of Ontario, Regulation 692 and Regulation 714/82. The types of hearing protection devices used shall also be provided in accordance with these regulations.

Table 3-3
Noise Exposure Levels

Column 1 Sound Level in Decibels	Column 2 Duration - Hours per 24-hour Day
90	8
92	6
95	4
97	3
100	2
102	1?
105	1
110	?
115	? or less
Over 115	No exposure

Note: "Decibel" means decibel measured on a type 2 sound
level meter conforming to the standard Z107.1 of
the Canadian Standards Association operating on the
A-weighing network with slow meter response.

3.3   RECORDKEEPING

Records of routine operation, receipt of materials, main-
tenance of specific equipment, unique operations, and
general inspections of the facility are used to:

°   Assess service levels and operating factors

o   Institute preventive maintenance programs

o   Train operating and maintenance personnel

o   Screen delivered materials for acceptable form and
packaging

o   Respond to special requests for service

o   Demonstrate compliance with health, safety, and
environmental standards

These records can be kept in the form of log sheets, log books, receipts, bills, purchase orders, certificates, and card files. There is also a considerable number of choices for automated recordkeeping tools. These include bar code generators, data loggers, microprocessor controller/recorders, and computers.

Chapter 4
INCINERATOR DESIGN AND OPERATION

4.1   INTRODUCTION

This chapter describes the design constraints and operating parameters of incinerators and incineration systems. Material and energy balances are presented, techniques for evaluating incinerator designs are developed, and operating parameters are discussed. It provides the user with not only a guide to current technology, but relatively easy-to-use methods of determining incinerator parameters.

4.1.1   Determining Waste Properties

Wastes are, by definition, non-uniform in quality. In order to proceed with equipment selection and design, however, waste characteristics must be determined or developed. Determination of waste properties can be made by referring to tabular data of materials, measurement of material properties, or, when waste analysis can be established, by calculating these properties. The determination of waste properties is of particular importance in addressing the Range of Operation aspects of Policy 01-01 (see Appendix B).

Incinerators should not be rated (specified) on the basis of performance on Type 0 or Type 1 waste. They should be rated and tested on the specific waste stream (e.g. refuse, Type 2, or Pathological, Type 4, wastes). If it can be clearly demonstrated that Type 2 or Type 4 wastes will never be fired in the incinerator, a detailed analysis (proximate and ultimate analyses) of the waste stream should be defined as the basis of performance of the incinerator.

4.1.1.1 Waste Characteristics

A waste material considered as an incineration candidate will normally have a combustible component, a non-combustible component, and may contain moisture. Generally, heating value is stated relative to the waste combustible component. Heating value can be noted as a gross number applied to the total waste quantity, but the combustible, non-combustible, and moisture components must be identified in order to determine the heat content of a material.

4.1.1.2 Tabular Values

Table 4-1 lists properties of various waste materials relative to incineration. Included are heating value, density, and typical ash and moisture components. Table 4-2 identifies common waste designations. Municipal solid waste composition in various locations is listed in Table 4-3 and Table 4-4 lists combustion characteristics of those wastes generated in the Hamilton area.

4.1.1.3 Laboratory Analyses

Proximate analysis and ultimate analysis are two widely accepted techniques used for the measurement of waste parameters.

Proximate Analysis. Proximate analysis as per ASTM D 3172 is a relatively quick and inexpensive laboratory determination of the percentages of moisture, volatile matter, fixed carbon, and ash. The analytic procedure is as follows:

Table 4-1
Characteristics of Selected Materials

Waste	Heating value as fired kJ/kg	Density kg/m^3	Content Weight Ash	Content Percent Moisture
Newspaper	18 600	110	1.5	6.0
Brown paper	16 900	110	1.0	6.0
Magazines	12 200	560	22.5	5.0
Corrugated paper	16 400	110	5.0	5.0
Plastic coated paper	17 100	110	2.6	5.0
Coated milk cartons	26 400	80	1.0	3.5
Citrus rinds	3 950	640	0.75	75.0
Shoe leather	16 800	320	21.0	7.5
Butyl sole composition	25 400	400	30.0	1.0
Polyethylene	46 500	960	0.0	0.0
Polyurethane (foamed)	30 200	32	0.0	0.0
Latex	23 000	720	0.0	0.0
Rubber waste	23 300	1 500	25.0	0.0
Wax (paraffin)	43 300	890	0.0	0.0
1/2 tar-2/3 paper	26 700	140	3.0	1.0
Tar or asphalt	39 500	960	1.0	0.0
1/2 tar-2/3 paper	25 600	240	2.0	1.0
Wood sawdust (pine)	22 300	180	3.0	10.0
Wood sawdust	19 000	180	3.0	10.0
Wood bark (fir)	22 100	260	3.0	10.0
Wood bark	19 200	260	3.0	10.0
Corn cobs	18 600	200	3.0	5.0
Rags (silk or wool)	21 000	200	2.0	5.0
Rags (linen or cotton)	16 700	200	2.0	5.0
Animal fats	39 500	880	--	0.0
Cotton seed hulls	20 000	440	2.0	10.0
Coffee grounds	23 200	440	2.0	20.0
Linoleum scraps	25 600	1 400	25.0	1.0

The above chart shows the various heating values of
materials commonly encountered in incinerator designs.
The values given are approximate and may vary based on
their exact characteristics or moisture content. The
heating value is the higher heating value.

Table 4-2
Ranges of Heating Values and Other Physical Characteristics for
The Types of Wastes Defined in Standard CSA Z103-1976

Type	Description	Moisture, Weight Percent Wet Basis	HHV kJ/kg Wet Basis	HHV kJ/kg Dry Basis	Bulk Density kg/m^3 as Fired
A	Cellulosic solids with up to 15% moisture	0-15	7900-27900	9300-27900	80-961
B	Cellulosic solids with 10-50% moisture	10-50	4600-20900	9300-27900	48-961
C	Cellulosic solids with over 40% moisture	40-80	2300-16700	9300-27900	48-993
D	Plastics and asphaltic solids, non-halogenated	0-30	17400-46400	18600-46400	32-1298
E	Plastics and asphaltic solids, halogenated	0-30	15800-30600	20400-30600	80-2307
F	Rubber	0-15	20200-36200	23600-36200	144-2003
G	Animal materials	5-85	2300-22000	23200	16-1298
H	Animal and human wastes	30-85	2300-20200	15600-28800	481-1282
I	Non-combustible solids	0-15	0	0	80-4486
J	Pathological materials	10-30	10400-18800	11600-20900	80-1041
K	Pathological remains	85	2300	23200	801-1202
L	Cadavers, coffin encased	40	13700	24100	641-1282
M	Organic liquids with under 30% water	0-30	70-39500	70-39500	721-1202
N	Organic liquids with over 30% water	30-80	700-27900	700-39500	641-1121
O	Fumes	0-80	1900-141600	9300-141600	0.64-5.45
P	Particulates, gas-borne	0-20	0-1200	0-1200	0.64-1.60
Q	Radioactive materials	0-50	0-46400	0-46400	32.0-8010
R	Special wastes	0-80	0-41800	0-41800	32-4486

Note: This table is from Incinerator Performance, CSA Standard Z103-1976

Table 4-3
Composition of Municipal Solid Waste
From Selected Locations
(percent wet weight)

Component	U.S. National Average (1)	Ontario Average (2)	Hamilton, Ontario (3)	Canada National Average (2)
Combustibles				
Paper	33.5	38.88	35.0	36.5
Food Waste	17.0	30.55	14.0	27.6
Yard Waste	17.5	3.30	13.0	6.1
Plastics	3.6	4.86	5.9**	5.2**
Rubber, Leather	2.6	-	-	-
Textiles	2.0	3.55*	2.7	4.3
Wood	3.2	3.36	5.2	4.2
Miscellaneous Organics	-	0.31	-	1.1
Total	79.4	84.81	75.8	85.0
Noncombustibles				
Glass, Ceramics	9.9	8.27	8.2	8.4
Metals	9.2	6.15	-	6.6
− ferrous	(8.0)	5.34	7.7	
− aluminum	(0.9)	(0.77)	-	
− other	(0.3)	(0.04)	0.7	
Fines	-	0.77	5.7	
Miscellaneous Organics	1.5	-	1.9	
Total	20.6	15.19	24.2	15.0

* includes rubber and leather
** includes rubber

References:

(1) Tenth Annual Report of the Council of Environmental Quality, Municipal Solid Waste, December 1979.

(2) Bird and Hale Ltd., Clarke Derszko and Associates Ltd., L.S. Love and Associates Ltd., Municipal Refuse Statistics for Canadian Communities of Over 10,000 (1976-1977), prepared for Environmental Protection Service, Environment Canada, 1979.

(3) Walls, T.B., Energy Recovery From Mass Burning of Municipal Solid Wastes, proceedings from Resource Recovery from Solid Wastes Conference, Miami Beach, Florida, May 1982.

Table 4-4
Combustion Characteristics of Municipal Solid
Waste Generated in the Hamilton Area

Ultimate Analysis	Percent by Weight
Carbon	18.5
Hydrogen	2.9
Nitrogen	0.5
Oxygen	23.0
Sulphur	0.1
Moisture	25.0
Ash	30.0
Total	100.0

Higher Heating Value (kJ/kg)	11,165

Proximate Analysis	Percent by Weight
Volatile Matter	38.5
Fixed Carbon	6.5
Moisture	25.0
Ash	30.0
Total	100.0

Reference: Walls, T.B., Energy Recovery From Mass Burning
of Municipal Solid Wastes

°   Heat a sample for one hour at 105°C to 110°C (221°F to
    230°F). Report the weight loss fraction as percent
    moisture.

°   Raise the temperature of the dried sample in a covered
    crucible to 725°C (1337°F) and hold it at this temper-
    ature for 7 minutes. Report the sample weight loss
    fraction as volatile matter percentage.

°   Ignite the remaining sample in an open crucible at
    950°C (1742°F) and allow it to burn to a constant
    weight. Report the sample weight loss as percent
    fixed carbon.

The sample residue is to be reported as percent ash. The
sum of moisture, volatiles, fixed carbon, and ash should
equal 100%.

Ultimate Analysis. Ultimate analysis is a standard pro-
cedure used for a determination of the quantities of
elemental components present in a sample (ASTM D 3176).
It is required in order to determine the products of com-
bustion of a material, its combustion air requirement, and
the nature of the off-gas or combustion products.

In this procedure the following element percentages are
normally determined:

°   Carbon
°   Hydrogen
°   Sulphur
°   Oxygen
°   Nitrogen
°   Halogens (chlorine, fluorine, etc.)
°   Heavy metals (mercury, lead, etc.)
°   Other elements that can affect the combustion process

In addition to these components, analyses may be performed under the heading of ultimate analysis for the presence of certain compounds that may be in the waste, such as chlorobenzene, chlorophenols, PCBs (polychlorinated biphenyls), dioxins, etc.

It must be recognized that wastes are often extremely heterogeneous in nature. The proper selection of a representative sample is at least as important as performing the test itself. Most commonly used methods involve dumping a truckload of material in an enclosed area, and then reducing the truckload to an approximately 100-kg sample by a process of repeatedly quartering the waste and discarding three-fourths. Generally, landfill equipment (a bulldozer or wheeled loader) is used for quartering. Alternative methods include selecting a random sample using a grid method, and treating the entire truckload as the sample.

After sample selection is completed, the material can be sorted into standard components (food wastes, paper, cardboard, plastics, textiles, rubber, leather, garden trimmings, wood, glass, non-ferrous metals, ferrous metals, dirt, ashes, etc.) so that each component can be analyzed.

4.1.1.4 Calculated Values

The approximate waste heating value can be calculated when the elemental conditions of the waste can be determined. If the fractions of carbon, hydrogen, oxygen, and sulphur can be determined, the DuLong equation can be used to approximate heating value. This equation is as follows:

$$Q = 33,829 \ C \ + \ 144,277 \ (H_2 - 0.125 \ O_2) \ + \ 9420 \ S$$

where Q is in kJ/kg and C, H_2, O_2, and S are the weight fractions of carbon, hydrogen, oxygen, and sulphur present. The weight fractions should add to 100% unless an inert material such as nitrogen is present. With the presence of nitrogen, for instance, the weight fraction (%) of C, H_2, O_2, and S will total 100% less the fraction of nitrogen present.

4.1.2   Waste Destruction Guideline

For domestic, biomedical, commercial and non-hazardous industrial waste, off-gases should pass through a zone of 1000°C (1832°F) minimum temperature (minimum) and should have a residence time within that zone of at least one second. (See Policy 01-01, Appendix B). Temperatures in excess of 1100°C (2012°F) should be avoided to minimize the potential for slagging. Oxygen measured at the exhaust of the incinerator should be a minimum of 6% (in situ, wet gas, by volume).

Incinerators should be operated at negative pressure to avoid the escape of incomplete combustion products. If provided, any emergency exhaust system should be located downstream of the afterburner.

Test burns should be performed to determine the appropriate temperature and residence time for industrial waste streams. In the absence of such data and as a first approximation when burning non-halogenated, non-polynuclear waste, a temperature of 1000°C (1832°F) should be maintained for a period of time of at least 2 seconds and with an oxygen content (as measured immediately downstream of the furnace section) of 3% minimum (dry volume). For polynuclear and for halogenated wastes, the minimum temp-

erature should be 1200°C (2191°F) with a residence time of
2 seconds and an oxygen content of the flue gas of 3% (dry
volume) minimum. For non-combustible wastes (such as
soils) contaminated with organics, the minimum off-gas
temperature should be no less than 700°C (1292°F) and the
minimum ash (residue) discharge temperature should be no
less than 550°C (1022°F) at the outlet of the incinerator
chamber where these materials are being fired. Note that
these are guidelines and that the required temperature,
residence time, and oxygen fraction must be determined
after an overall design and process review, which should
include performance of test burns.

4.1.3   Design Calculations

Important parameters of incinerator design and operation
include the temperature that waste will burn at without
the addition of supplemental fuel, whether supplemental
fuel is required for waste destruction, the quantities of
air required, and the amount of flue gas generated from
the burning waste.

4.1.3.1 Adiabatic Temperature

The temperature at which a waste will burn without consid-
ering process losses is its adiabatic temperature. These
process losses would include radiation losses from the
furnace walls and heat lost in the ash discharge. The
adiabatic temperature is a function of the waste combust-
ible heating value, waste combustible content, moisture
content, and excess air requirement. As a first-order
approximation of adiabatic temperature for any combustible
material, the as-received waste heating value can be used.
Figure 4-1 is a graph of adiabatic temperature versus
gross (as-received or as-fired) heating value for various
values of excess air. It is applicable for any material,
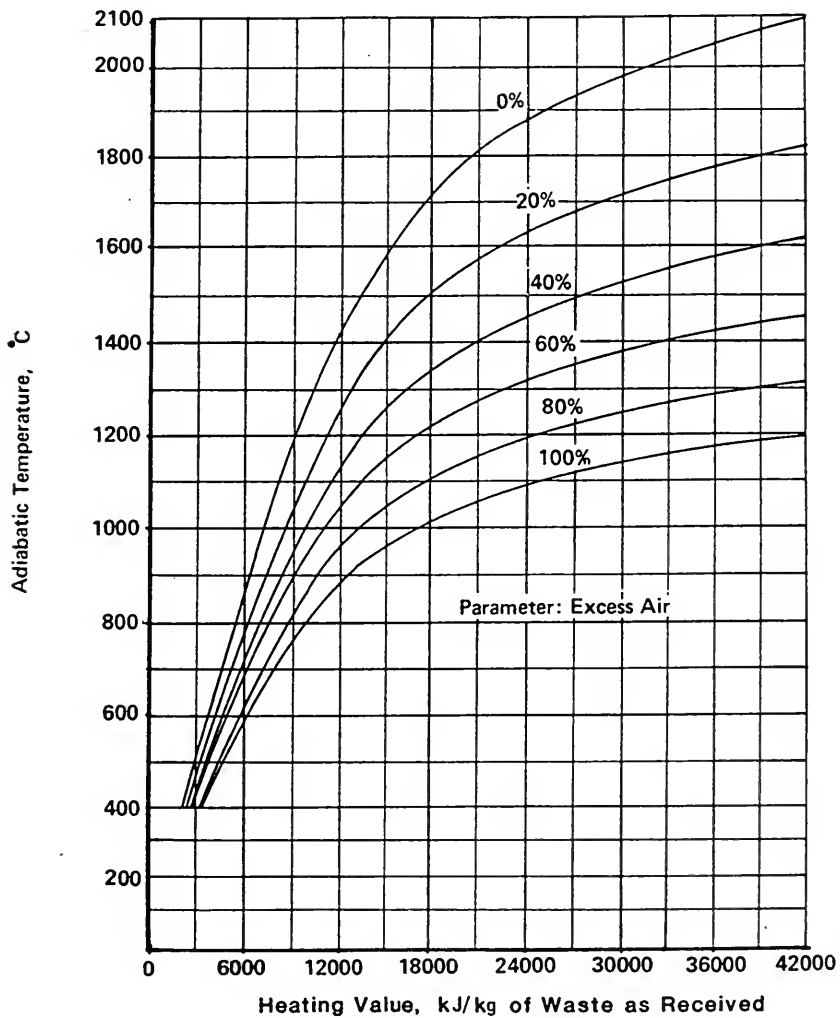
Figure 4-1

ADIABATIC TEMPERATURE VS. EXCESS AIR

liquid, solid, or gas. Excess air values for typical fur-
naces are given in Table 4-5.

<div align="center">

Table 4-5
Typical Excess Air Values

</div>

Incinerator Type	Excess Air Range
Fluid bed	40% - 60%
Gaseous waste	10% - 15%
Liquid waste	15% - 30%
Multiple chamber (Retort, in-line)	100% - 200%
Multiple hearth	100% - 125%
Rotary kiln	100%
Waterwall	65% - 100%

Using Figure 4-1, for example, a waste with an as-received
heating value of 8000 kJ/kg (3440 Btu/lb) is burned in a
fluid bed incinerator using 60% excess air. As an exam-
ple, combustion of this waste is assumed to require 1000°C
(1830°F) for effective destruction. From the graph, the
adiabatic temperature is approximately 900°C (1650°F), and
therefore, supplemental fuel is required to achieve a com-
bustion temperature of 1000°C (1830°F).

This graph gives an approximate temperature of combustion
and provides an indication of whether or not to proceed
with a detailed analysis of incinerator parameters.

4.1.3.2 Incinerator Analysis

There are a number of incinerator parameters that are nor-
mally of interest, including the following:

°   Furnace temperature
°   Supplemental fuel requirement

° Combustion air requirement
° Flue gas discharge quantity
° Residence time
° Turbulence/mixing

From these parameters, sizes of equipment associated with the incinerator system can be calculated.

Table 4-6 represents a step-by-step method of analysis for an incinerator system. It is a simplified mass and heat balance. The feed quantity, moisture fraction, non-combustible fraction, and combustible heating value must be known. An excess air and humidity figure must be selected as well as a reasonable radiation figure (from 1% to 5% of the total heat release) and an ash heat content (ash will normally represent a heat loss in the range of 160 to 340 kJ/kg [69 to 146 Btu/lb] of ash). The required gas temperature for destruction of the waste stream must be selected.

This analysis is a detailed heat balance based on the principle that the total heat leaving (exiting) a system is equal to the heat entering that system. Heat entering a system includes the potential heat release of a waste, and/or fuel, that is fired within that system.

One important assumption made in this analysis is that flue gas from an incinerator is composed of moisture plus dry air. Actual incinerator off-gas contains more carbon dioxide and less oxygen than is found in air. The assumption that dry flue gas has the properties of air, however, greatly simplifies calculations while introducing a relatively small error (less than 3%) in calculated temperatures and heat requirements.

Table 4-6
Incinerator Analysis

1.	Feed quantity (as-received)	_____ Given
2.	Moisture fraction	_____ Given
3.	Moisture quantity (kg/h)	_____ 1 x 2
4.	Solids quantity (kg/h)	_____ 1 - 3
5.	Noncombustible fraction	_____ Given
6.	Noncombustible quantity (kg/h)	_____ 4 x 5
7.	Combustible quantity (kg/h)	_____ 4 - 6
8.	Heating value (kJ/kg combustible)	_____ Given
9.	Total heat generated (kJ/h)	_____ 7 x 8
10.	Stoichiometric air ratio (kg/kg combustible)	_____ Figure 4-2a
11.	Stoichiometric air (kg/h)	_____ 7 x 10
12.	Excess air fraction	_____ Given
13.	Excess air (kg/h)	_____ 11 x 12
14.	Total air required (kg/h)	_____ 11 + 13
15.	Moisture generated (kg/kg combustible)	_____ Figure 4-2b
16.	Moisture generated (kg/h)	_____ 7 x 15
17.	Humidity (kg/kg dry air)	_____ Given
18.	Humidity (kg/h)	_____ 14 x 17
19.	Total moisture (kg/h)	_____ 3 + 16 + 18
20.	Dry flue gas (kg/h)	_____ 7 + 14 - 16
21.	Radiation heat loss (kJ/h)	_____ Given
22.	Ash heating value (kJ/kg)	_____ Given
23.	Ash heat loss (kJ/h)	_____ 6 x 22
24.	Humidity correction (kJ/h)	_____ 18 x 2186
25.	Miscellaneous heat loss (kJ/h)	_____ Given
26.	Heat in flue gas (kJ/h)	_____ 9 - 21 - 23 + 24 - 25
27.	Flue gas temperature (°C)	_____ 19, 20, 26
28.	Required gas temperature (°C)	_____ Given
29.	Required flue gas heat content (kJ/h)	_____ 19, 20, 28
30.	Heat required (kJ/h)	_____ 29 - 26
31.	Fuel excess air	_____ Given
32.	Fuel required (l or m³/h)	_____ Figure 4-3a or 4-3b,30,31
33.	Air for fuel (kg air/l or m³)	_____ Table 4-5,31
34.	Air required (kg/h)	_____ 33 x 32
35.	Moisture from fuel (kg/l or m³)	_____ Table 4-5, 31
36.	Moisture generated (kg/h)	_____ 35 x 32
37.	Dry gas from fuel (kg/l or m³)	_____ Table 4-5, 31
38.	Dry gas generated (kg/h)	_____ 37 x 32
39.	Total dry gas flow (kg/h)	_____ 38 + 20
40.	Total moisture flow (kg/h)	_____ 35 + 19
41.	Total heat at exit (kJ/h) gross htg value)	_____ 26 + 32 x (Fuel)

Air quantities required to support combustion must be
determined to perform these calculations. If the exact
waste composition is known, the air requirements can be
determined by calculation from the equilibrium equations,
as follows:

For combustion of carbon,

$$C + O_2 \rightarrow CO_2$$
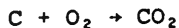
For combustion of hydrogen,

$$H_2 + ?O_2 \rightarrow H_2O$$

For sulphur,

$$S + O_2 \rightarrow SO_2$$
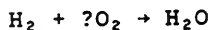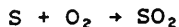
With each kg of oxygen, nitrogen is present in air,

1 kg air = 0.2315 kg O_2 + 0.7685 kg N_2
1 kg oxygen carries 3.3197 kg nitrogen from air

Usually there is some uncertainty about the range of waste
composition and properties. The curves in Figures 4-2 and
4-3 were generated based on the DuLong equation (see
Section 4.1.1.4). Using this equation, a relationship
between gas composition and heating value was established
and plotted (Figure 4-2 relates the stoichiometric air
requirements to heating value; Figure 4-3 relates moisture
produced from combustion to heating value). These values
are approximate, recognizing that the DuLong equation
represents only an estimate of heating value.

Figures 4-4 and 4-5 and Table 4-7 indicate the net heat
available from supplemental fuel combustion in an inciner-
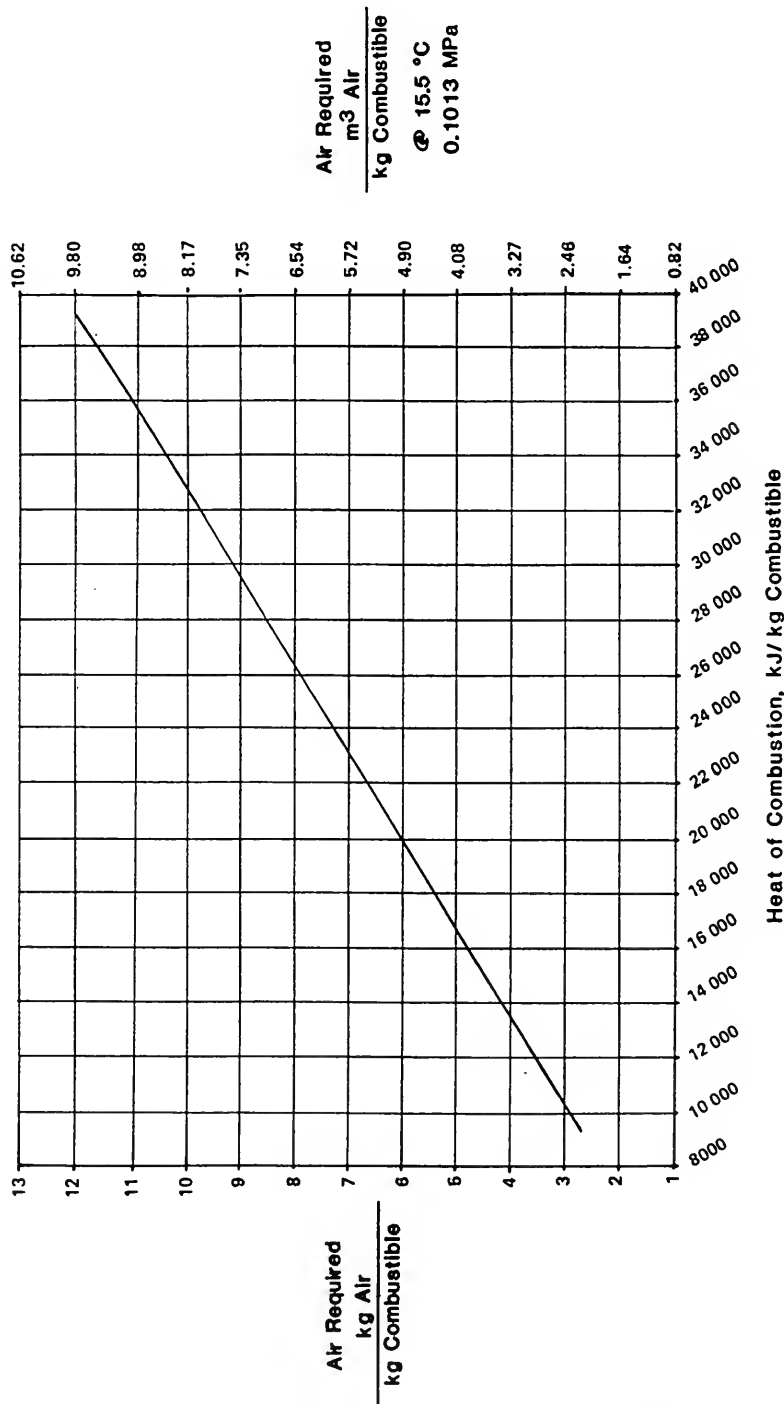
Figure 4-2

AIR REQUIRED, STOICHIOMETRIC COMBUSTION
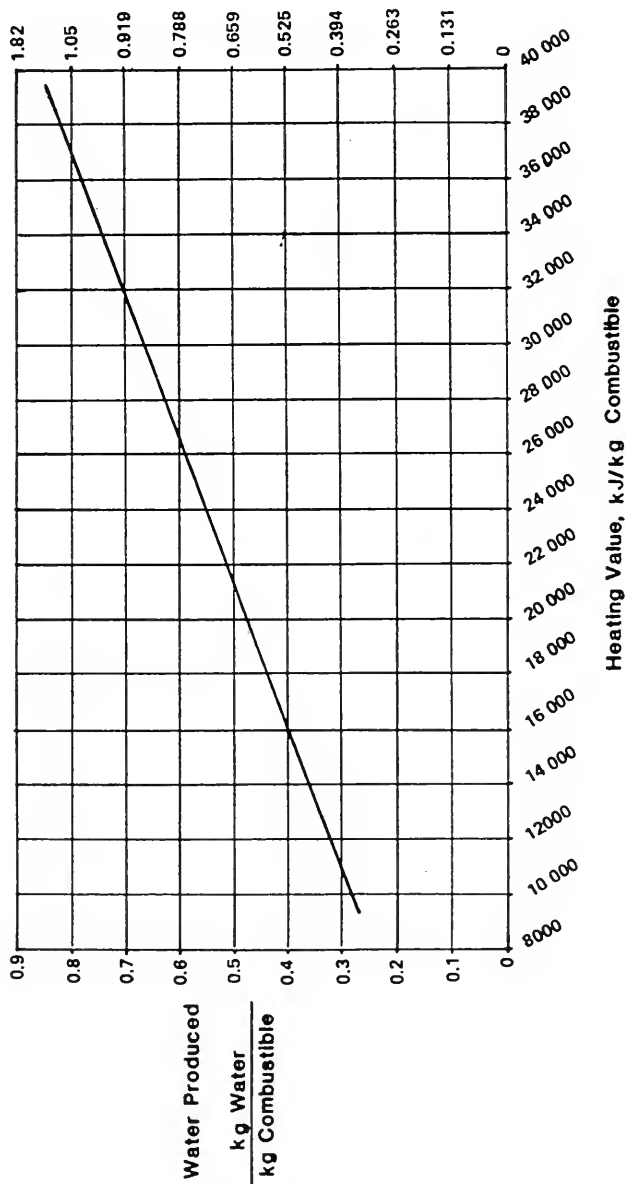
Figure 4-3
WATER PRODUCED FROM COMBUSTION
(Zero Humidity)
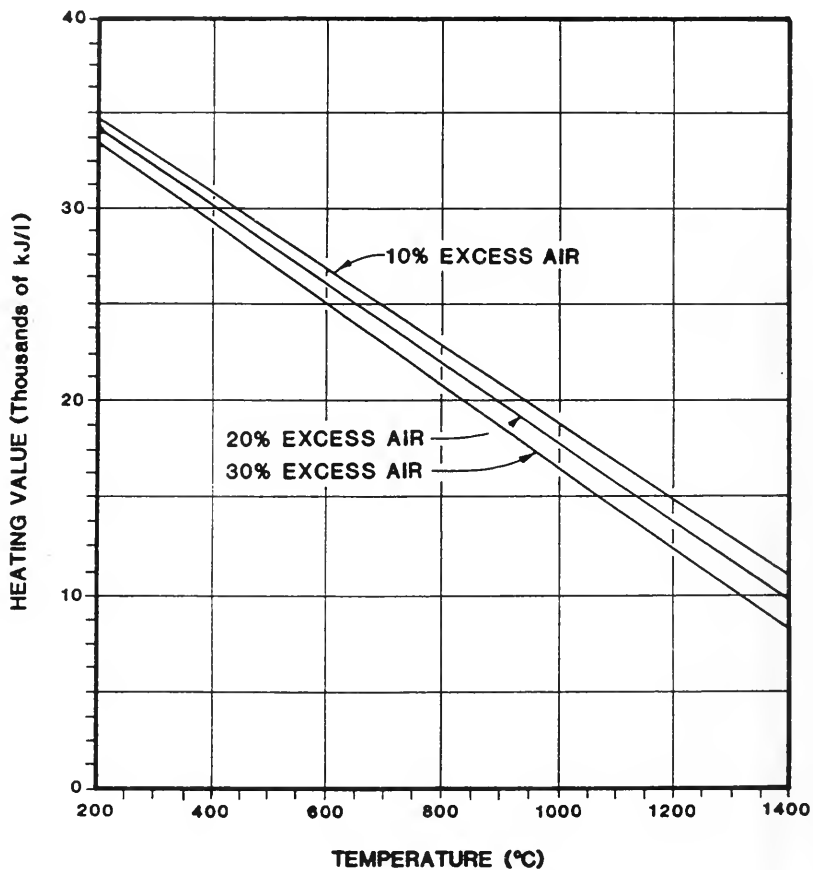
Figure 4-4
NET HEAT AVAILABLE, No. 2 FUEL OIL
FOR 10, 20, 30% EXCESS AIR
AS A FUNCTION OF TEMPERATURE
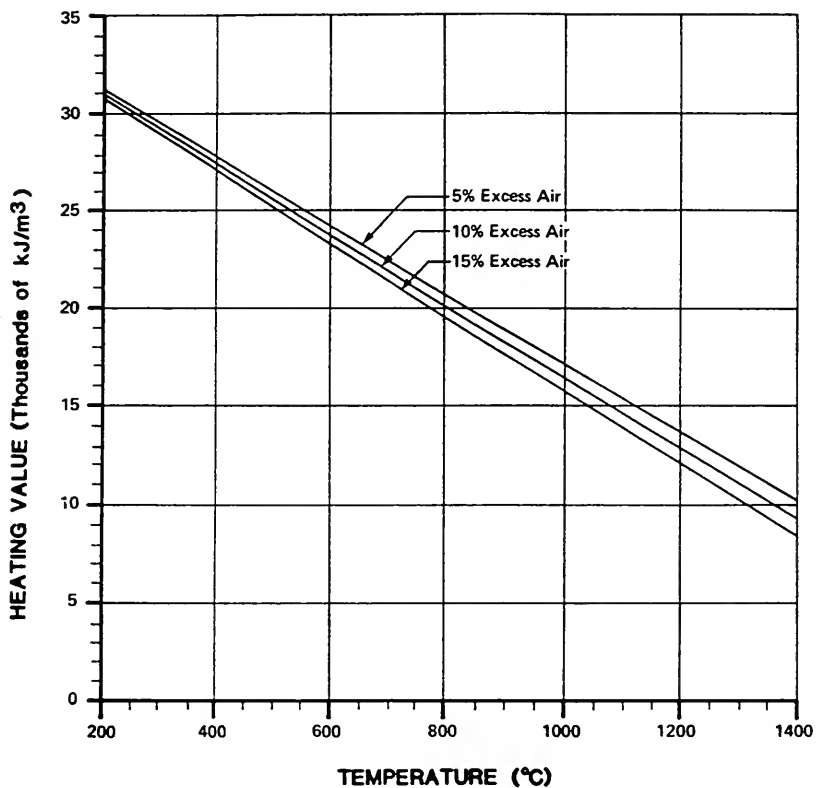
Figure 4-5

NET HEAT AVAILABLE, NATURAL GAS
FOR 5, 10, 15% EXCESS AIR
AS A FUNCTION OF TEMPERATURE

Table 4-7
Supplemental Fuel Combustion

No. 2 Fuel Oil, Heat Content of 39 100 kJ/l,
Density of 0.91 kg/l

	Total Air		
Percent Excess Air	10	20	30
kg air/l	13.78	15.03	16.29
kg dry gas/l*	13.84	15.09	16.34
kg water/l*	1.04	1.05	1.07

Natural Gas, Heat Content of 37 256 kJ/m^3,
Density of 0.80 kg/m^3

	Total Air		
Percent Excess Air	5	10	15
kg air/cubic metre gas	12.09	12.66	13.24
kg dry gas/cubic metre gas*	11.40	11.97	12.55
kg water/cubic metre gas*	1.65	1.65	1.66

* Products of Combustion

ation process. As the temperature of the process (the
incinerator exit temperature) increases, the heat required
to raise the temperature of the products of combustion of
supplemental fuel to the incinerator exit temperature
increases. The heat available for process heating (the
net heating value) is the heat of combustion of the fuel
less heat lost to products of combustion of supplemental
fuel. The available heat, therefore, decreases with
increasing temperature, as shown in Figures 4-4 and 4-5
for No. 2 fuel oil and natural gas. This net heating
value must be used in incinerator calculations.

A detailed example of an analysis of an incineration sys-
tem is included in Appendix C.

4.1.4   System Design Features

After design calculations have been performed, system
design can proceed. System design includes incinerator
chamber sizing, fan sizing, flue sizing, etc.

4.1.4.1   Duct Sizing

Ducts convey air and are normally sized to provide no more
than 12 m/s (40 ft/s) air flow velocity. Higher veloci-
ties result in excessive noise and excessive pressure
drop.

4.1.4.2   Flue Sizing

Flues carry gaseous products of combustion (flue gas) from
the incinerator. They generally are sized to allow no
more than 9 m/s (30 ft/s) gas flow. At higher velocities
the particulate normally present in the exhaust will tend
to accelerate flue erosion.

Table 4-8
Typical Heat Release Rates

Incinerator	Heat Release
* Fluid Bed	350 000 − 500 000 $\dfrac{kJ}{m^2\text{-}h}$ bed area
Multiple Chamber	300 000 − 400 000 $\dfrac{kJ}{m^3\text{-}h}$
Multiple Hearth	300 000 − 400 000 $\dfrac{kJ}{m^3\text{-}h}$
* Multiple Hearth	250 000 − 350 000 $\dfrac{kJ}{m^2\text{-}h}$ hearth area
Gaseous Waste Incinerator	3 000 000 − 10 000 000 $\dfrac{kJ}{m^3\text{-}h}$
Liquid Waste Incinerator	1 000 000 − 3 000 000 $\dfrac{kJ}{m^3\text{-}h}$
Rotary Kiln	500 000 − 1 500 000 $\dfrac{kJ}{m^3\text{-}h}$
* Solid Waste Grate	150 000 − 300 000 $\dfrac{kJ}{m^2\text{-}h}$ grate area

* These heat release values are based on surface area, not volume

4.1.4.3   Chamber Sizing

Chamber sizing is based on heat release. There is a limit
to the quantity of heat that can be released in a particu-
lar furnace chamber. Heat release is that amount of heat
generated when combustible material burns. When combust-
ible gases burn or when liquids burn in suspension, the
volume of the furnace chamber will limit the total amount
of heat released within that chamber. The furnace volume
must be large enough to allow release of the heat gener-
ated by the anticipated waste and the supplemental fuel.

When a solid or sludge waste is fired, the heat release
(heat generated per chamber volume or hearth area per
hour) of that waste is characterized by the area of the
surface on which it is placed, i.e., the hearth or grate.

Table 4-8 lists typical heat release values for some com-
mon incinerator systems. The calculated heat release is
determined by dividing the value in step 41 of Table 4-4
(which includes heat released from the waste plus the heat
release from supplemental fuel) by the hearth or grate
area (or chamber volume).

Heat release rates for multiple chamber incinerators and
starved air units have been considered in developing the
design data on Figures 4-11, 4-12, and 4-14.

As an example of the use of this information, a reasonable
size of a rotary kiln used for destruction of 2000 kg/h
(4410 lb/hr) waste with a heat content of 17 000 kJ/kg
(7309 Btu/lb) is calculated as follows:

$$2000 \ \frac{kg}{h} \times 17 \ 000 \ \frac{kJ}{kg} = 34 \ 000 \ 000 \ \frac{kJ}{h}$$

Using a 1 000 000 $\frac{kJ}{m^3-h}$ heat release rate,

34 000 000 $\frac{kJ}{h}$ ÷ 1 000 000 $\frac{kJ}{m^3-h}$ = 34 m²
(1200 ft³)   volume

For a kiln with a 2.5-m internal diameter (Unit Cross Sectional Area = 4.91 m²), the required length is

$\frac{34 \text{ m}^3}{4.91 \text{ m}^2}$ = 6.93 m (22.7 ft)

The kiln for this application would have an internal diameter of 2.5 m (8.2 ft) and a length of 7.0 m (23 ft).

4.1.4.4 Turbulence and Mixing

In order to achieve high combustion efficienices in incinerators, it is particularly important to achieve good mixing between the primary combustion products (primarily CO and organics) and a stoichiometric excess secondary combustion air. This mixing can be promoted by a range of physical parameters as well as by promoting highly turbulent flow of the gases. Physical parameters which are used to promote mixing include:

° location and direction of secondary air jets;
° volume and pressure of secondary air addition;
° changes in flow direction(s);
° other baffling techniques;

As well as the provision of overall mixing using the above methods, the eddies formed by turbulent flow promote local mixing of the combustible gases and air. The degree of
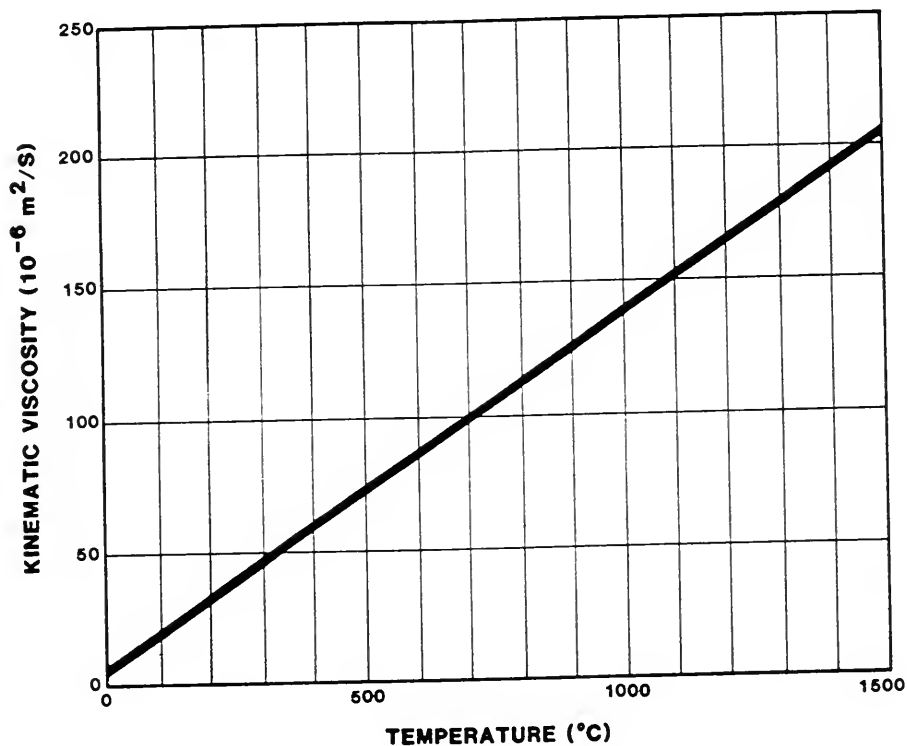
Figure 4-6
KINEMATIC VISCOSITY OF AIR vs TEMPERATURE

turbulence is typically assessed by use of the Reynolds
Number, N_{RE}:

$$N_{RE} = \frac{VD}{K}$$

where V = average velocity, m/s
       D = diameter (or equivalent diameter) of flow
          stream, m
       K = kinematic viscosity, m^2/s, Figure 4-6

When the Reynolds number is below 2300 (defined as the
critical Reynolds number), flow is generally considered
laminar with no significant turbulence.

As a guide, the gas flow within an incinerator chamber or
flue should have a Reynolds number well above 10,000. As
an example of this calculation, assume a flue exiting a
furnace has an internal diameter of 2 m (6.6 ft). The gas
flow is at a temperature of 1000°C (1832°F), and is at a
velocity of 10 m/s (33 ft/s). From Figure 4-6, K = 140 x
10^{-6} at 1000°C. Therefore:

$$N_{RE} = \frac{VD}{K} = \frac{10 \text{ m/s x 2 m}}{140 \times 10^{-6} \text{ m}^2/s}$$

$$N_{RE} = 143\ 000$$

A Reynolds Number of 143,000, in combination with good
mixing, should be ample to provide high combustion effic-
iency and burnout.

For a rectangular or other shape of flue, the equivalent
diameter (D_e) should be used. For example, for a rec-
tangle, D_e is equal to four times the cross-sectional
area divided by the wetted perimeter, i.e.

$$D_e = \frac{2*ab}{a+b}$$

where a and b are the dimensions of the sides of the rectangle.

In this example, a = 2 m and b = 3 m.

Therefore, $D_e = \frac{2 \times 2 \times 3}{2 + 3} = 2.4$ m

This value of D_e would be used in lieu of D when applied to a non-circular cross section.

4.1.4.5 Fan Sizing

The fan power requirement is a function of air or gas flow rate (cubic metres per second), the pressure developed across the fan (kilopascals), and the fan efficiency. The efficiency of fans located downstream of air pollution control systems (clean gas) are normally in the range of 80 to 85%; fans located upstream of control devices (dirty gas) require specific designs which may be limited to the range of 60 to 75% efficiency. Efficiency will also drop as the fan becomes dirty, or when fan material erodes with wear. The fan power consumption is calculated as follows:

$$S \quad = \quad \frac{QWp}{h}$$

Q   =   flow rate, m^3/s

Wp   =   pressure across fan, kPa

h   =   fan efficiency

S   =   fan power consumption, kW

The flow rate of air or gas is determined from the incin-
erator calculations procedure described above. Typical
pressure drops for fans associated with incinerator sys-
tems are listed in Table 4-9. These pressure values are
values developed across the fan and should be used as Wp
in the above equation.

Table 4-9
Typical Fan Pressure Drop Values

Fan Type	Pressure Drop
Forced Draft	1.0 - 1.5 kPa
Heated Gas Recirculation	1.0 - 2.0 kPa
Induced Draft	5.0 - 15.0 kPa
Supplemental Fuel Combustion Air	0.2 - 0.5 kPa
Fluidizing Air Blower	1.2 - 5.0 kPa

Note: The above values are typical of the pressure drop
       across a particular fan usage that should be used
       in determining fan power requirements.

4.1.4.6 ID Fan Sizing

An induced draft fan (ID fan) is the fan at the discharge
of an incinerator that draws flue gas from the incinerator
and discharges the gas through a stack to atmosphere.
Many incinerators such as multiple hearth furnaces, grate
type systems, and rotary kilns use ID fans.

Hot exhaust gases leaving incinerators may be first cooled
by passage through a heat recovery section and/or passage
through a water quench. Normally, sufficient water will
be added to the hot gas stream to saturate that gas stream
before entering the ID fan. When a fabric filter or an
electrostatic precipitator is included within the system,

only a limited amount of water is added; the gas flow would not be saturated and less water would be required.

Figure 4-7 relates the gas flow rate of saturated gas to dry air flow as a function of temperature. Determination of this ratio is necessary to allow a determination of the fan size. As noted previously, the assumption that flue gas has a dry component with the properties of dry air is used in these calculations.

As an example, if an ID fan is placed downstream of a wet scrubber which passes 18 000 kg/h (39,683 lb/h) of dry gas at a temperature of 50°C (122°F) entering the ID fan, the flow rate is calculated as follows:

From Figure 4-7, at 50°C (122°F), one kg of dry air will have a volume of 1.03 m^3 (36 ft^3) when saturated with water. The 18 000 kg/h dry gas will, therefore, produce 18 000 kg/h x 1.03 m^3/kg, or 18 540 m^3/h of flue gas entering the ID fan. The ID fan can be sized on the basis of this flow.

4.1.4.7 Electric Power Requirements

As a general rule, when an ID fan is used in an incineration system, the total electric power requirements of that system can be approximated as double the ID fan rated kW. If an ID fan is not used, the power rating of each of the major items of equipment must be determined and totaled to obtain the facility power requirement.

4.1.5   Refractory Selection

4.1.5.1 Refractory Parameters

There are a wide variety of refractory and insulation products available. Their significant properties include:
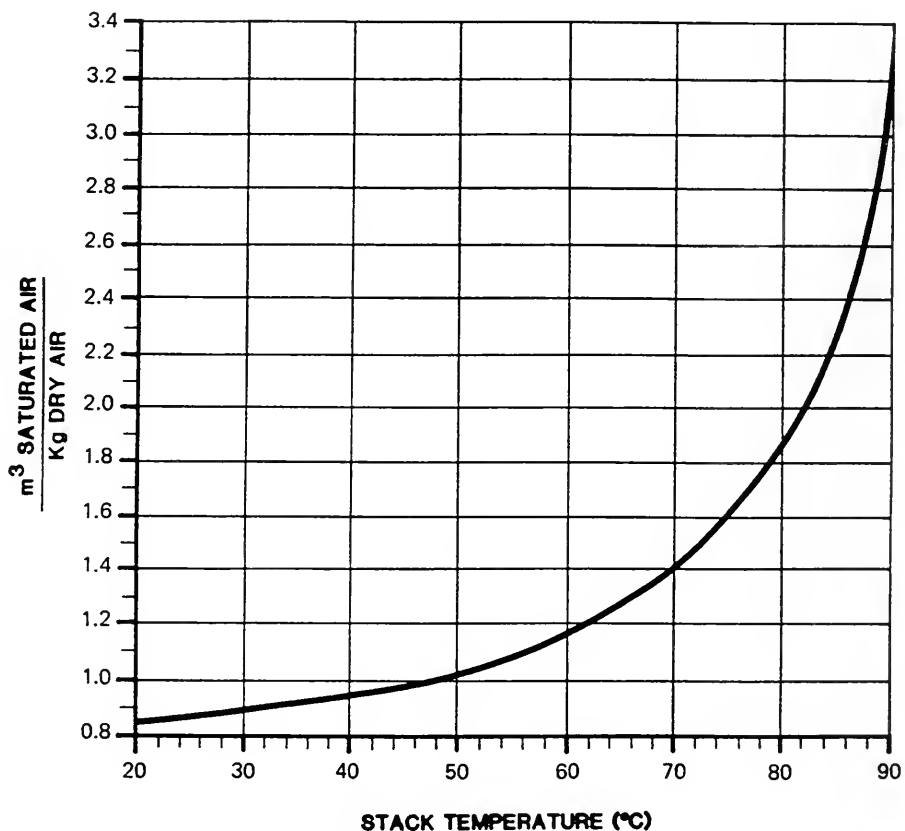
Figure 4-7

AIR HANDLING REQUIREMENTS FOR INDUCED DRAFT FANS
CUBIC METRES SATURATED AIR PER KILOGRAM DRY AIR
AS A FUNCTION OF STACK TEMPERATURE

o   Abrasion - the washing away or physical destruction of
    material under forces due to physical contact with the
    gaseous, liquid, or solid materials on the hot face.

o   Resistance to slagging or corrosion - the chemical
    process that destroys the refractory bond or the chem-
    ical integrity of the insulation.

o   Mechanical shock or cold crushing strength - the
    ability to withstand handling and shipping without
    damage and impact strength at low temperature opera-
    tions.

o   Modulus of rupture - a standard measure of structural
    strength provided by load testing (ASTM Methods C16
    and C216), providing another measure of mechanical
    shock resistance.

o   Spalling - a deterioration of the surface of the
    refractory by flaking caused by abrasion, corrosion,
    mechanical or thermal shock.

o   Porosity - the susceptibility to penetration by slags
    or gases, indicative of fly ash adherence.

o   Maintaining strength under high temperature condi-
    tions.

o   Insulating value - the ability to provide resistance
    to the flow of heat.

o   Reheat (ASTM Method C113) - a measure of irreversible
    changes in linear dimensions under repeated heating
    and cooling.

°   Specific heat - the amount of heat required to raise
    the temperature of a refractory material.

°   Thermal expansion - the reversible change in linear
    dimensions under heating and cooling. Where refrac-
    tory is used as a liner in a flue, for instance, the
    expansion of the refractory must be evaluated with
    respect to thermal expansion of the flue; if the
    expansions do not match, provision for material expan-
    sion must be considered.

°   Resistance to the operating environment. Of particu-
    lar interest is the performance of refractory in an
    oxidizing or reducing atmosphere; a reducing atmos-
    phere, one deficient in oxygen, will tend to degrade
    refractory material containing iron or silicon
    components.

4.1.5.2 Castables (Refractory Concrete)

These materials are supplied dry and are to be mixed with
water before installation. They are installed by either
pouring (casting in place), troweling, pneumatic gunning
(as with gunned fireproofing), or ramming. A castable
refractory should provide a smooth, continuous, monolithic
mass. Castable materials are normally placed in an area
with pins, mesh, or other anchor devices to hold the
refractory in place during placement and curing. Mesh,
grid, studs, or needles may also be used to enhance the
strength of the refractory installation.

Castable refractories are classified as dense or light-
weight (insulating). Dense castables have excellent mech-
anical strength and low permeability. Their insulating
properties, however, are relatively poor. As dense mater-
ials, over 1600 kg/m³ (100 lb/ft³) specific weight, they

offer good resistance in wet service such as quencher linings.

Lightweight castables are excellent insulators. Castable materials have the advantage of relatively easy installation in irregular areas such as furnace transitions, burner openings, etc. Lightweight castable service temperatures are limited generally to below 1650°C (3000°F) whereas other castable refractories can sustain higher temperatures.

4.1.5.3 Firebrick

Conventional firebrick is kiln baked to uniform, controlled consistency and quality. The term firebrick refers to dense brick, over 1600 kg/m³ (100 lb/ft³) containing up to 44% alumina, normally placed in direct contact with the hot gas stream. Conventional firebrick has relatively poor insulating qualities.

Insulating firebrick (IFB) is a lightweight, porous brick, normally less than 800 kg/m³ (50 lb/ft³), which can be placed in direct contact with the gas stream and which provides good insulating characteristics. IFB is machined to its final shape providing excellent dimensional control as compared to conventional firebrick which is used as-cast.

IFB is lower in structural strength than firebrick and, because of its porosity, is a soft material not suitable for erosive gas streams, i.e., gas streams with high particulate components. This low abrasion resistance limits the maximum velocities allowed adjacent to it.

Where refractory brick is required and high abrasive resistance is necessary, firebrick will often be provided

with insulation block as backup between the firebrick and the furnace/flue wall.

Silicon carbide refractory has relatively good thermal conductivity, good mechanical resistance, and abrasion resistance.

There are numerous types and grades of firebrick such as super-duty (high alumina content, improved strength and stability properties at high temperature), high-duty (good thermal shock resistance), low-duty (applicable for lower temperature and low abrasion service), and silicon carbide (excellent resistance to chemical attack), etc.

4.1.5.4   Incinerator Refractory Selection

Table 4-10 describes typical refractory applications for various incinerator sections.

4.1.6   Exhaust Gas Monitoring

Permanently mounted instrumentation is required for the measurement of temperatures, total hydrocarbons (or carbon monoxide), and opacity. Additionally, oxygen, carbon dioxide, and nitrogen oxides monitoring may be required.

As a minimum, temperature should be monitored and recorded for the gas leaving the furnace and the exhaust gas exiting the stack. Gaseous monitors should be located as close as practicable to the furnace exhaust point.

Special care must be exercised in locating opacity meters on systems which incorporate wet gas cleaning devices (such as a venturi scrubber). Entrained and/or condensing moisture downstream will appear and will affect the

Table 4-10
Refractory Selection for Incinerators

Incinerator Part	Temperature (°C) Range	Abrasion	Slagging	Mechanical Shock	Spalling	Fly Ash Adherence	Recommended Refractory
Charging gate	20-1400	Severe, very important	Slight	Severe	Severe	None	Super-duty
Furnace walls, grate to 2 m above	20-1400	Severe	Severe, very important	Severe	Severe	None	Silicon carbide or superduty
Furnace walls, upper portion	20-1400	Slight	Severe	Moderate	Severe	None	Super-duty
Stoking doors	20-1400	Severe, very important	Severe	Severe	Severe	None	Super-duty
Furnace ceiling	20-1400	Slight	Moderate	Slight	Severe	Severe	Super-duty
Flue from combustion chamber	650-1400	Slight	Severe, very important	None	Moderate	Moderate	Silicon carbide or superduty
Combustion chamber	650-1400	Slight	Moderate	None	Moderate	Moderate	Super-duty
Combustion chamber ceiling	650-1400	Slight	Moderate	None	Moderate	Moderate	Super-duty
Breeching walls	650-1650	Slight	Slight	None	Moderate	Moderate	Super-duty
Breeching ceiling	650-1650	Slight	Slight	None	Moderate	Moderate	Super-duty
Subsidence chamber walls	650-1650	Slight	Slight	None	Slight	Moderate	Firebrick or Super-duty
Subsidence chamber ceiling	650-1650	Slight	Slight	None	Slight	Moderate	Firebrick or Super-duty
Stack	260-540	Slight	None	None	Slight	Slight	Firebrick or Super-duty

opacity reading. An upstream location will provide on
indication of particulate and other carryover from the
incinerator.

4.1.7   Acid Gas Corrosion

The exhaust gases from incinerators usually contain HCl,
SO_2 and other acidic gases. Special design considerat-
ions may be necessary where:

- ° gas temperatures will be below 150°C (300 °F; pot-
  ential for acid gas condensation) and/or
- ° heat recovery media (e.g. boiler tubes) will be
  above 370°C (700°F; potential for acid gas
  corrosion)

4.2   INCINERATOR SYSTEMS

4.2.1   Mass Burn Incinerators

The term "mass burn incineration" describes the process by
which bulk, heterogeneous solid waste is fed and burned
as-received without pretreatment or pre-sorting. Several
types of incineration equipment can be used to accomplish
this task, from the simplest single-chamber units through
to multi-chamber incinerators and large central waste
incineration systems. The principal types of mass-burning
incineration equipment are described below.

4.2.1.1 Single-Chamber Incinerators

Equipment Description. A typical single-chamber incinera-
tor is shown in Figure 4-8. Solid waste is placed on the
grate and ignited. Combustion air is induced to flow into
the combustion chamber through the underfire and overfire
ports and up the stack into the atmosphere. Underfire air
provides oxygen to burn the waste, while the overfire air
supply promotes combustion of the flue gas. Ash falls
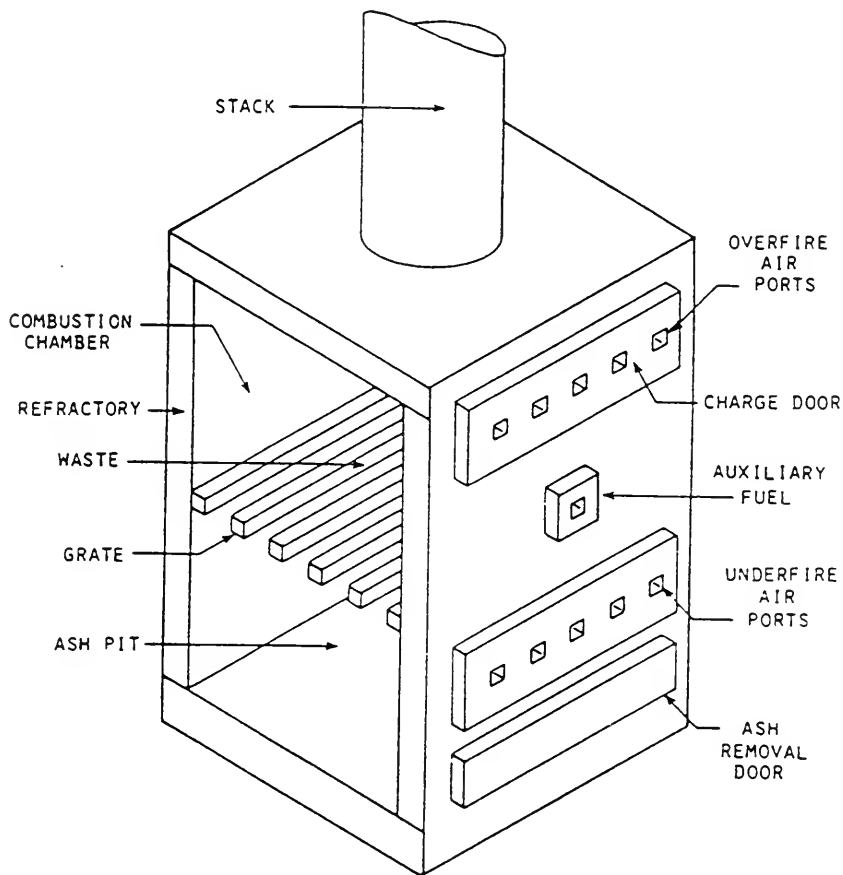
Figure 4-8
SINGLE CHAMBER INCINERATOR

through the grate to an ash pit and is manually removed at the conclusion of a burn.

The single-chamber incinerator is typically operated on a batch-charged basis; it is provided with an auxiliary fuel burner; and it may have an afterburner within the stack to reduce the emissions of unburned carbonaceous particles and hydrocarbon gases.

Application. Single-chamber incinerators have been used for combustion of virtually all types of solid waste. If the waste material does not have sufficient heat value to support its own combustion, the unit must be equipped with an auxiliary fuel burner.

Development Status. Various designs of the single-chamber incinerator have been used in applications such as the flue-fed apartment building incinerator for burning domestic waste, or the teepee burner for destruction of refuse, wood, and agricultural waste. The largely uncontrolled nature of the combustion process in these units has led to a decrease in their popularity with the advent of more stringent air pollution control standards. In particular, flue-fed incinerators are frequently prohibited due to the potential for overloading and piling of the waste. Air distribution is generally poor in this equipment, resulting in poor combustion and the generation of smoke and odour.

Operating Practice. Due to the significant variation in design of single chamber incinerators and the lack of control over combustion air feed rates, it is difficult to cite generic operating practice for this incinerator type. However, in general most systems operate at between 100% and 300% excess air. Systems equipped with afterburners normally maintain a temperature of 750°C to 1000°C (1380°F to 1830°F) for 0.5 to 1.0 seconds to reduce stack emissions.

Guideline. Single chamber incinerators should be replaced by a modern package unit which meets current guidelines, or alternate arrangements made to dispose of the wastes. Consideration might be given to upgrading units to meet the aspects of Policy 01-01 and 01-03 but it is highly unlikely that such conversion would be practical or economical.

Single chamber incinerators should not be used for industrial wastes, pathological wastes, or wastes containing hazardous or toxic constituents.

4.2.1.2 Multiple-Chamber Incinerators

Equipment Description. To overcome the problem of incomplete combustion associated with single-chamber incinerators, multiple-chamber units were developed. A primary chamber is used for combustion of the solid waste while the secondary chamber provides the residence time, temperature, and supplementary fuel for combustion of the unburned products carried over from the primary chamber.

There are two basic types of multiple-chamber incinerators, retort and in-line systems:

°   Retort Incinerator: This unit is a compact incinerator in the form of a cube with multiple internal baffles. The baffles are positioned to guide the combustion gases through 90° turns in both lateral (horizontal) and vertical directions. At each turn, ash (soot) drops out of the flue gas flow. The primary chamber has elevated grates for burning of the waste and an ash pit for collection of ash residue. A cutaway view of a typical retort incinerator is shown in Figure 4-9.
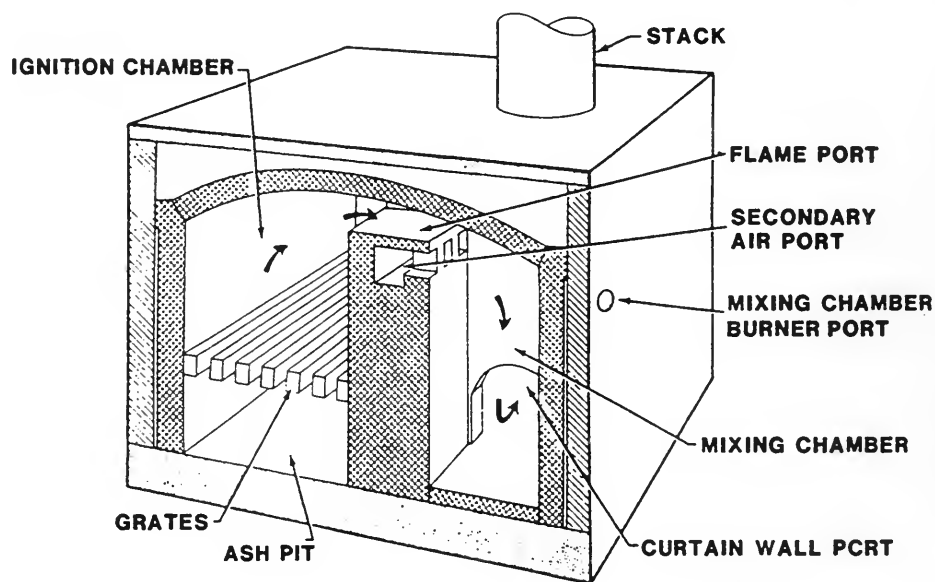
Figure 4-9
RETORT INCINERATOR

°   In-Line Incinerator: This is a larger unit than the
     retort incinerator. Flow of combustion gases is
     straight through the incinerator axially, with abrupt
     changes in direction as shown in Figure 4-10. Waste
     is charged on the grate, which can be either station-
     ary or moving. As with the retort type, changes in
     the flow path and flow restrictions in an in-line
     incinerator provide settling out of larger airborne
     particles and increased turbulence for more efficient
     burning.

With both types of systems, supplemental fuel burners are
provided in both the primary and secondary chambers.
Depending upon the nature of the waste burned, the fuel
supply in the primary chamber may be unnecessary after
startup although the secondary chamber normally requires a
continuous fuel supply (at least a pilot flame). Overfire
and underfire air to the primary chamber is normally
aspirated through ports in the wall of the furnace, or is
supplied at a controlled rate by forced draft fans.
Additional air is added to the secondary chamber to ensure
complete combustion.

Application. Multiple-chamber incinerators are commonly
used for all types of solid waste as well as for specialty
applications such as incineration of pathological wastes,
crematory incinerators, and metal drum reclamation.

Development Status. Multiple-chamber incinerators are
commercially available, many as packaged systems. Retort
incinerators are normally used for batch or semi-continu-
ous operation in the capacity range of 10 to 350 kg/h (22
to 772 lb/hr). In-line incinerators are normally provided
in the 225 to 900 kg/h (496 to 1,984 lb/hr) range and may
be equipped with automatic charging and/or ash removal
equipment on units above 20 kg/h (44 lb/hr) capacity.
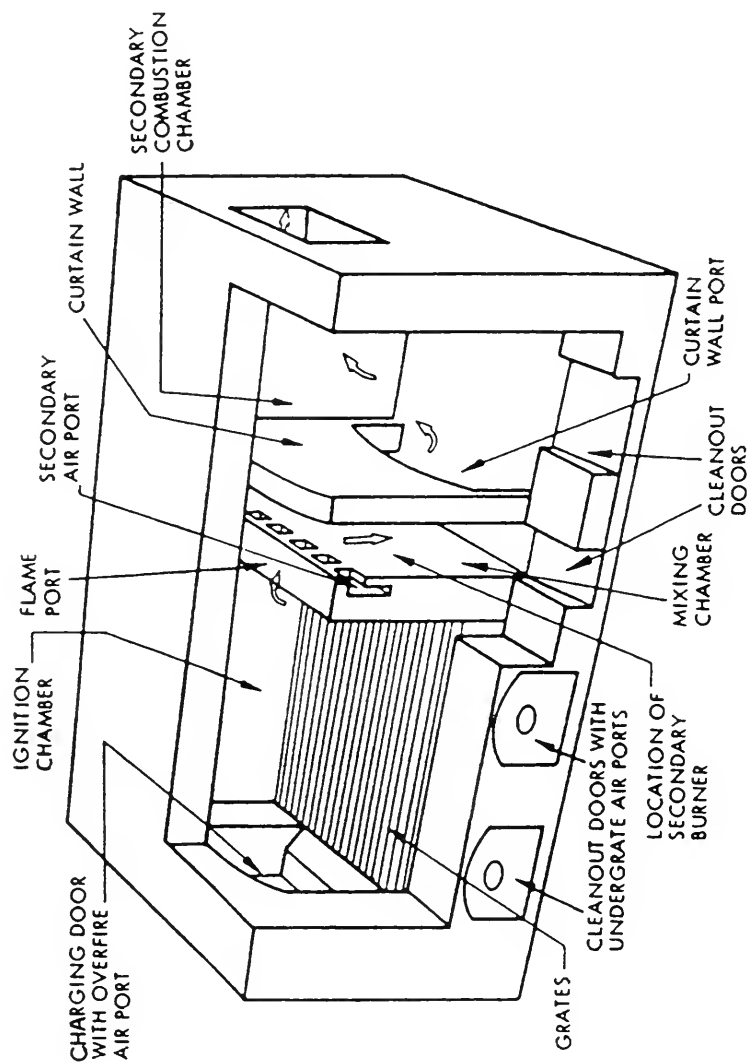
Figure 4-10
IN-LINE INCINERATOR

SECONDARY COMBUSTION CHAMBER

CURTAIN WALL

CURTAIN WALL PORT

CLEANOUT DOORS

MIXING CHAMBER

LOCATION OF SECONDARY BURNER

SECONDARY AIR PORT

FLAME PORT

IGNITION CHAMBER

CLEANOUT DOORS WITH UNDERGRATE AIR PORTS

GRATES

CHARGING DOOR WITH OVERFIRE AIR PORT

Operating Practice. Dimensional data for typical retort and in-line incinerators of varying capacity are provided in Figures 4-11 and 4-12, respectively. Although they represent the product of a single manufacturer, the dimensional data can be considered generic. They are typically operated at a temperature of 760°C to 1000°C (1400°F to 1832°F) in the secondary chamber and normally use approximately 200% excess air. Approximately half of the required air enters as leakage. Of the balance, 70% should be provided in the primary combustion chamber as overfire air, 10% as underfire air, and 20% in the mixing or secondary chamber.

They are applicable for refuse, trash, rubbish and biomedical waste, but it is generally difficult to incorporate the air emission control equipment required to meet Policy 01-10.

Guideline. Multiple-chamber incinerators should meet all the aspects of Policy 01-01 and 01-03 and the additional aspects as discussed in Section 4.1.2.

As well when burning biomedical waste, a grate should not be used. A solid hearth to support the waste is acceptable. The operating temperature should be no less than 760°C (1400°F) in the primary chamber and 1000°C (1830°F) minimum in the secondary combustion chamber.

4.2.1.3 Pyrolysis Systems

Process Description. Pyrolysis is the destruction of carbonaceous material in the presence of heat and substoichiometric oxygen level. In practice the heat is provided by combustion of a portion of the waste. Under ideal conditions, the pyrolysis of pure cellulose will produce

1. STACK
2. SECONDARY AIR PORT
3. GAS BURNERS
4. ASH PIT CLEANOUT DOOR
5. GRATES
6. CHARGING DOOR
7. FLAME PORT
8. UNDERFIRE AIR PORT
9. IGNITION CHAMBER
10. OVERFIRE AIR PORT
11. MIXING CHAMBER
12. COMBUSTION CHAMBER
13. CLEANOUT DOOR
14. CURTAIN WALL PORT

PLAN VIEW

SIDE ELEVATION

END ELEVATION
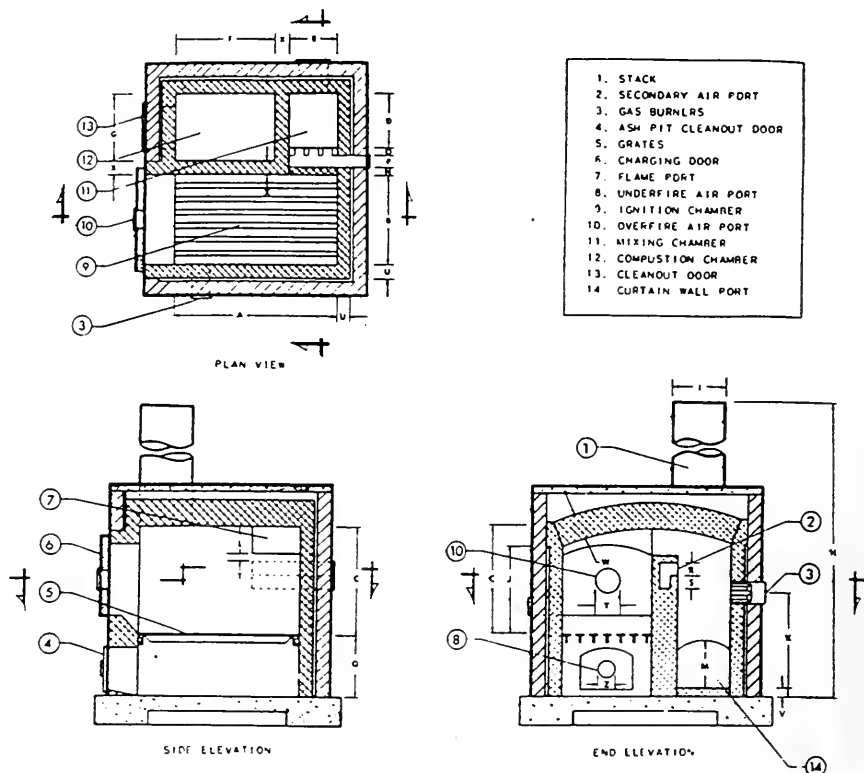
DESIGN STANDARDS, MULTIPLE CHAMBER RETORT INCINERATORS, DIMENSIONS IN CENTIMETERS

INCINERATOR SIZE (KG/HR)	A	B	C	D	E	F	G	H	I	J	K	L	M
25	80	34	57	23	17	51	34	548	20	47	51	10	25
45	103	46	72	34	23	69	46	579	30	58	71	13	38
70	114	57	85	39	29	74	57	609	36	69	90	13	42
110	137	69	95	46	34	91	69	670	46	76	101	19	46
225	194	91	120	69	46	126	91	853	61	93	123	32	58
340	217	125	137	91	57	137	114	975	76	101	130	38	71
450	240	137	151	91	69	149	114	1060	86	114	138	44	76

INCINERATOR SIZE (KG/HR)	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
25	11	6	6	23	6	6	6.35	114	6	11	11	15	10
45	6	6	10	37	13	0	6.35	114	6	11	11	20	13
70	11	6	11	46	13	6	6.35	114	6	11	11	23	15
110	11	11	11	51	13	6	6.35	114	6	11	11	30	15
225	23	11	11	66	13	13	6.35	228	11	23	23	41	20
340	23	11	11	64	13	25	6.35	228	11	23	23	46	20
450	23	11	11	70	19	32	6.35	228	11	23	23	56	25

Figure 4-11
DIMENSIONAL DATA FOR RETORT INCINERATORS

PLAN VIEW

SIDE ELEVATION
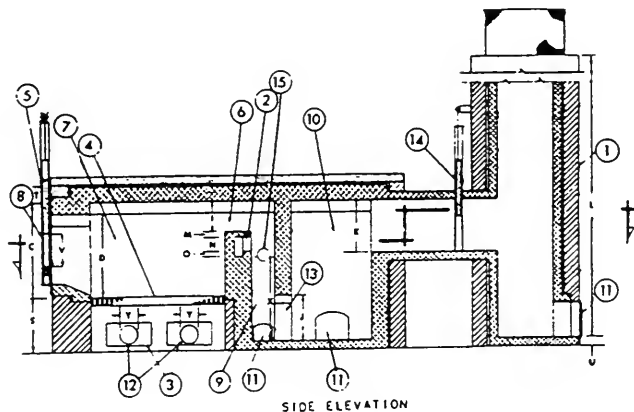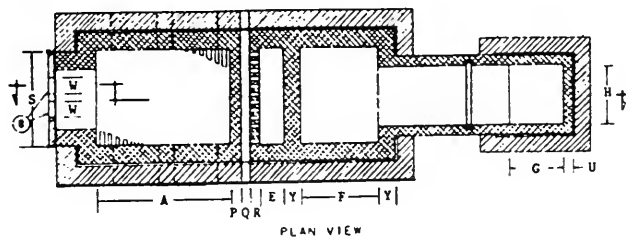
1. STACK	6. FLAME PORT	11. CLEANOUT DOORS
2. SECONDARY AIR PORTS	7. IGNITION CHAMBER	12. UNDERFIRE AIR PORTS
3. ASH PIT CLEANOUT DOORS	8. OVERFIRE AIR PORTS	13. CURTAIN WALL PORT
4. GRATES	9. MIXING CHAMBER	14. DAMPER
5. CHARGING DOOR	10. COMBUSTION CHAMBER	15. GAS BURNERS

DESIGN STANDARDS: MULTIPLE-CHAMBER, INLINE INCINERATORS, DIMENSIONS IN CENTIMETERS

INCINERATOR SIZE (KG/HR)	A	B	C	D	E	F	G	H*	I	J	K	L	M
407.7	217	126	131	114	40	137	69	69	24	61	46	10	11
543.6	240	137	137	121	46	15	80	80	28	74	57	11	11
815.4	251	194	165	140	46	183	91	91	32	81	69	12	11
1087.2	274	229	177	146	57	202	103	103	38	91	80	12	11

INCINERATOR SIZE (KG/HR)	N	O	P	Q	R	S	T	U	V	W	X	Y
407.7	13	19	23	6	6	76	23	11	13	28	130	18
543.6	13	25	23	6	6	76	23	11	18	30	132	20
815.4	13	19	23	11	11	76	23	11	20	36	156	23
1087.2	13	25	23	11	11	76	23	11	23	38	161	25

* DIMENSIONS IN THIS COLUMN ARE IN METERS

Figure 4-12
DIMENSIONAL DATA FOR IN-LINE INCINERATORS

combustible off-gases (methane and carbon monoxide), water
(steam), and a residual char (carbon). The ideal pyroly-
sis reaction, of which there are many variations, is as
follows:

$$C_6H_{10}O_5 \rightarrow CH_4 + 2CO + 3H_2O + 3C$$
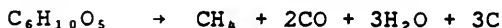
In the actual destruction of waste, the off-gases are a
mixture of many simple and complex volatile organic com-
pounds, and the char is often a liquid containing residual
carbon or tars and ash. In general, volatile gas produc-
tion increases with increasing temperature, whereas the
generation of tars and other liquors is greatest at lower
temperatures.

Application. The only commercial pyrolysis system that
has been found to operate successfully in North America is
one that handles industrial semi-liquid and sludge wastes
at a number of pharmaceutical plants in the United States.
The use of pyrolysis for the destruction of municipal
sludge and solid wastes has not been successfully demon-
strated to date on a commercial scale.

Development Status. Pyrolysis has been used as an indus-
trial process for many years for the production of char-
coal from wood chips, coke and coke gas from coal, fuel
gas and pitch from heavy hydrocarbon still bottoms, etc.
The process has seen promotion for waste destruction only
since the late 1960s. Commercial pyrolysis systems for
municipal waste destruction, such as Union Carbide's PUROX
process, the ANDCO-TORRAX process, and Monsanto's Land-
guard system, are no longer actively marketed in North
America.

Operating Practice. Pyrolysis reactors typically operate
at temperatures of between 500°C and 900°C (930°F and

1650°F) with waste residence times of 12 to 15 minutes. Systems designed to generate heat internally by combustion use less than the stoichiometric oxygen requirement. Depending on the waste characteristics and process design features, off-gas will typically have a heating value of between 5000 and 15 000 kJ/m³ (134 to 403 Btu/ft³) which represents about 80% of the heat energy originally contained within the waste. The solid residue normally represents less than 5% of the original waste volume although pyrolysis systems will have a higher fixed carbon content than excess air incinerators. Pyrolysis units have been found to be applicable to the destruction of organic industrial sludges.

A number of problems have been found in the application of pyrolysis systems to the destruction of solid waste. The temperatures developed in the reactor are sufficiently high to keep the ash and other residue components molten. It has been difficult in many of these systems to control the solidification of the molten material as it leaves the reactor. Excessive slagging has occurred at the residue outlet and this slag, which is a result of uneven cooling of the molten ash, clogs the reactor, preventing ash discharge. The reactor must be shut down until the slag formation has been removed.

Another problem that has been found with pyrolysis systems is the generation of small particulate matter and organics in the off-gas. The nature of the pyrolysis reaction is that it does not burn the waste; it thermally decomposes the waste, generating a fairly dirty exhaust stream rich in organics and containing significant amounts of small carbonaceous solid particles. An afterburner must be employed to burn out organics in the off-gas.

Most pyrolysis systems include an emergency exhaust stack that is used to bypass critical equipment when operating problems occur such as a loss of cooling water in downstream equipment or the failure of the induced draft fan. An emergency exhaust stack must never be placed upstream of the afterburner. This stack discharges to atmosphere and the hot gases, which are rich in organics, will burn upon contact with a source of air (or oxygen). Placing an exhaust stack between the pyrolysis reactor and the afterburner will result in, at best, uncontrolled burning out the stack, and at worst, the discharge of organics which may pose a threat to human health. There is also a high probability that such a discharge will result in an explosion as the hot organic-laden gases react with the surrounding air.

A Japanese firm has developed a sludge incineration system (multiple hearth furnace) that is designed specifically for operation in the pyrolysis mode. It has a minimal amount of openings in its shell, and an afterburner is included as an integral part of the furnace structure. An American firm has also developed a sludge pyrolysis system which is in use treating sludge from pharmaceutical operations. This furnace is a single rotary hearth unit, with an afterburner slightly removed from the furnace itself. Careful attention is paid to minimizing air leakage into the system. Without dedicated designs such as these, the use of pyrolysis for waste disposal can result in severe problems. Modification of an existing multiple hearth furnace, for instance, from excess-air operation to pyrolysis operation is difficult and dangerous. The furnace contains numerous openings which are potential sources of uncontrolled air infiltration. For instance, the accidental opening of an access door or opening a damper too far or too quickly which admits air to the furnace can result in a conflagration.

Guideline. Pyrolysis reactors should meet all the aspects
of Policy 01-01 and 01-03, and the additional aspects dis-
cussed in Section 4.1.2. The specific treatment of the
pyrolysis gas (e.g. removing condensibles) should be cons-
idered in developing the combustion and air pollution re-
quirements for the fuel gas produced.

4.2.1.4 Starved Air Incinerators

Equipment Description. Starved Air or Controlled Air
incinerators, also referred to as Modular Combustion Units
(MCUs), are two-chamber incinerators in which less than
the stoichiometric air requirement is provided in the
primary chamber. The thermal reactions occurring in this
chamber are a combination of combustion and pyrolysis.
The products of the pyrolysis reaction (typically methane
and carbon monoxide off-gases and unburned carbon) flow to
a secondary chamber where excess air is added, also at a
controlled rate, to effect complete combustion. The com-
bustion process is so well controlled with these units
that very low particulate emissions may be achieved.

Figure 4-13 illustrates some typical configurations of
controlled air incinerators.

Application. MCUs were originally developed for the des-
truction of paper waste. They are also applicable to the
destruction of other solid wastes and their secondary
chamber can be used for the destruction of gaseous or
liquid waste in suspension. Work has been done on the
incineration of sewage sludge with municipal refuse in an
MCU with limited success.

The nature of the MCU process is such that agitation of
the waste feed is minimal. Materials requiring agitation
for effective combustion, such as powdered carbon or pulp
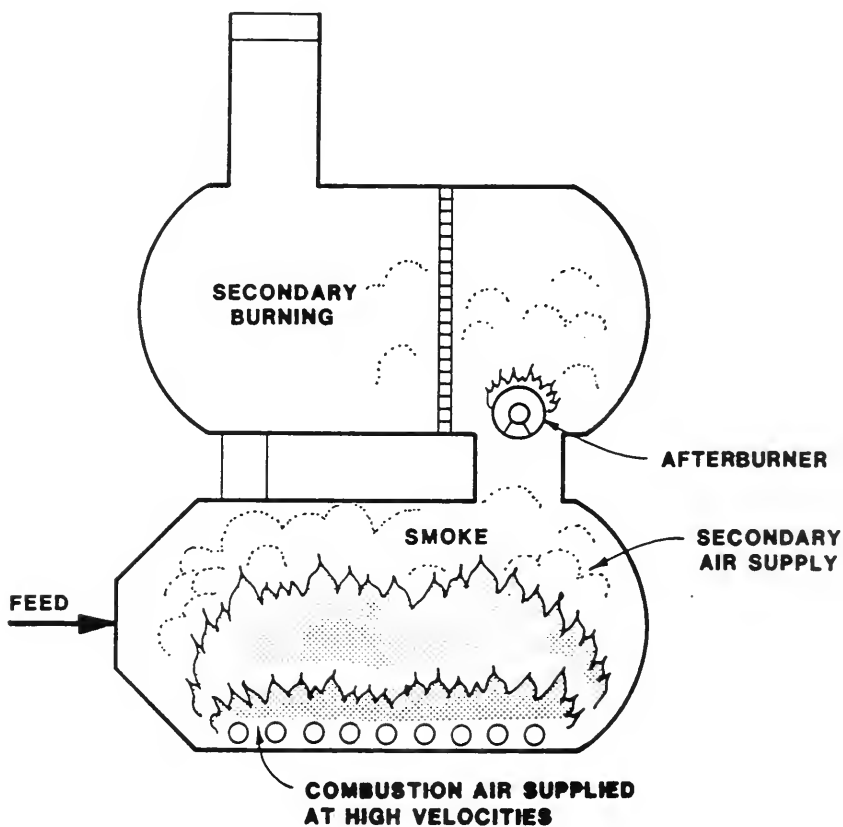
Figure 4-13

MODULAR CONTROLLED-AIR INCINERATOR CONFIGURATION

wastes, are not appropriate candidates for incineration in an MCU.

Development Status. MCUs are manufactured by several vendors as "standard" models that are modified to suit a customer's specific needs (e.g. waste type, heat recovery requirements, etc.). Smaller units, under 340 kg/h (750 lb/hr), are normally batch fed using a hopper/ram assembly or double ram charging system to minimize the infiltration of air into the primary chamber during charging.

Larger units are usually provided with a continuous waste charging system, a screw feeder, or a series of moving grates. Ash removal from smaller units is usually a manual operation, whereas larger systems may be equipped with automatic ash removal and quenching equipment.

Operating Practice. Most of these units are provided with heat recovery. Normally, firetube boilers are used for the generation of steam or hot water. Dimensional data for a typical MCU system are shown in Figure 4-14. This equipment, although provided by a single manufacturer, can be considered generic. The temperature in the primary chamber is usually maintained in the range of 760°C to 870°C (1400°F to 1600°F), whereas the secondary chamber may operate at temperatures as high as 1100°C (2010°F). With paper-type wastes the secondary chamber temperature has typically been in the 870°C to 1000°C (1600°F to 1830°F) range.

Typically 70 to 80% of the stoichiometric air requirement is introduced into the primary chamber. Approximately 140 to 200% of the primary chamber's off-gas stoichiometric requirement is fed to the secondary chamber. The net air flow to the system is in the range of 100% to 200% of the stoichiometric requirement.
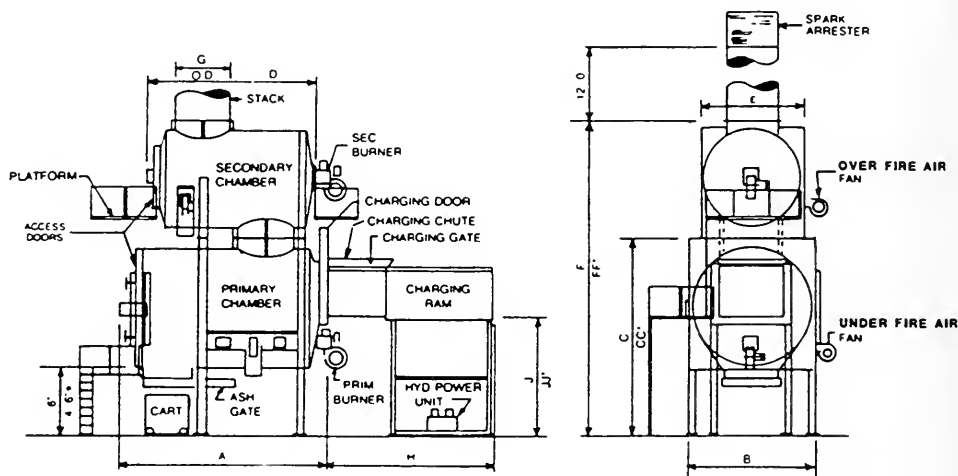
DESIGN STANDARDS: TYPICAL MODULAR COMBUSTION UNTIS, DIMENTIONS IN METERS

CAPACITY (KG/HR)	A	B	C	CC	D	E	F	FF	G	H	J	JJ	CHUTE CAPACITY (m³)
45- 75	2.6	1.4	1.5	2.7	1.9	1.1	2.7	4.0	0.4	3.4	0.6	1.8	0.4
100- 160	2.9	1.7	1.8	3.0	2.1	1.4	3.4	4.6	0.5	3.4	0.6	1.8	0.4
145- 240	2.9	1.8	2.0	3.2	2.1	1.7	3.8	5.0	0.5	3.4	0.8	2.0	0.8
200- 320	3.0	2.0	2.1	3.4	2.4	1.7	4.0	5.2	0.7	3.4	0.8	2.0	0.8
300- 475	3.5	2.3	2.4	3.7	2.4	1.8	4.6	5.8	0.8	4.0	0.8	2.0	1.5
400- 635	3.7	2.4	2.6	3.8	2.7	2.0	4.9	6.1	0.9	4.0	1.1	2.4	1.5
600- 950	3.8	2.9	3.0	4.3	2.9	2.6	5.9	7.2	1.0	4.0	1.1	2.6	2.3
885-1450	4.4	3.2	3.4	4.6	3.0	2.9	6.6	7.8	1.2	4.0	1.2	2.7	2.3
1050-1775	4.9	3.4	3.5	4.7	3.7	2.9	6.7	7.9	1.3	4.3	1.7	2.9	3.1
1300-2150	5.5	3.5	3.7	4.9	4.3	2.9	6.9	8.1	1.4	4.3	1.7	2.9	3.1

Figure 4-14
DIMENSIONAL DATA FOR TYPICAL MCU SYSTEM

Air feed rate to each chamber is controlled by temperature. Below the stoichiometric air requirement (in the primary chamber) temperatures increase with increasing airflow, whereas in the secondary chamber, where excess air is provided, increasing airflow decreases the operating temperature. Automatic fan damper positioning is normally used to control the airflow and, thus, temperature in each chamber.

MCUs are applicable to trash in all incinerator sizes. In larger sizes (over one tonne per hour), they are applicable to refuse burning. They have limited application in industrial waste disposal and have demonstrated mixed results in the disposal of biomedical wastes.

Starved air units require close control of air injection into the furnace, particularly into the primary chamber. Any uncontrolled source of air (such as through the charging door or around the ash discharge ram) will increase burning and will reduce the heating value of the gas stream entering the secondary chamber. Normally, the secondary chamber is provided with burners sized to burn out flue gas with a significant organic content. It will not have sufficient heat release to effectively burn out gas without significant organic content. The more air introduced into the primary chamber, the poorer the waste destruction in the primary chamber and the more difficult it is to destroy organics in the secondary chamber.

Air infiltration is difficult to control. The starved air furnace is operated under negative pressure to prevent leakage of hot, dirty flue gases from the furnace. An air lock system should be provided on the charging door, which typically opens from four to ten times per hour, staying open from 30 seconds to 1-1/2 minutes per charge. Like-

wise, the ash ram system should be provided with an air lock.

Starved air systems are sometimes specified on the basis of trash or pure paper waste. This is not a realistic means of selection. These wastes are rarely, if ever, found. If sized on these high quality wastes, the furnace will generally not have sufficient supplemental fuel heat output to effectively destroy wastes normally found, such as refuse or garbage (cafeteria wastes). This equipment should be specified for a capacity to incinerate an actual waste stream, not a theoretical superior waste.

Guideline. Controlled air incinerators should meet all requirements of Policy 01-01 and 01-03 and the additional aspects discussed in Section 4.1.2. As well when burning biomedical waste, a grate should not be used. A solid hearth to support the waste is acceptable.

The operating temperature should be in the range of 400°C to 760°C (750-1400°F) in the primary chamber.

An air lock system should be provided with controlled air units of 500 kg/h (1,102 lb/hr) capacity or less to reduce infiltration of air into the unit. This system must include dual charging rams as well as duplicate charging doors. Alternate designs may be considered if they can be demonstrated to be as effective as double rams.

4.2.1.5 Central Waste Incinerators

Equipment Description. Central waste incinerators are those which accept waste from several external sources for destruction in a central facility. They are usually

large, (in excess of 50 t/d [55 T/d]) continuously operat-
ed installations equipped with heat recovery equipment.
Waste is burned in these incinerators without pre-process-
ing.

The features of large central mass burning incinerators
are distinguished by the design of the grate system. The
grate must transport refuse through the furnace and pro-
mote combustion by providing adequate agitation without
contributing to excessive particulate emissions.

European systems are typically equipped with inclined
grates that move the waste through the furnace by recipro-
cating or rotating drum action as illustrated in
Figure 4-15. Stationary circular grates with rotating
rabble arms, travelling grates, and rocking grates are
also used.

As the waste moves progressively through the furnace, it
is dried, burned, and combusted to ash. Approximately 40
to 60% of the total air entering the furnace is provided
as underfire air to cool the grates and prevent ash slagg-
ing. The balance is supplied as overfire air to complete-
ly combust the flue gas and particulate rising from the
grates.

Many central waste incineration systems are built with
waterwall construction in addition to boiler tubes within
the flue gas steam (convection sections) to maximize ener-
gy recovery from the incinerator. Refractory-lined
combustion chambers with a separate downstream boiler sec-
tion may also be used in lieu of waterwall construction.
If refractory walls are used, higher excess air is requir-
ed to control the operating temperature.
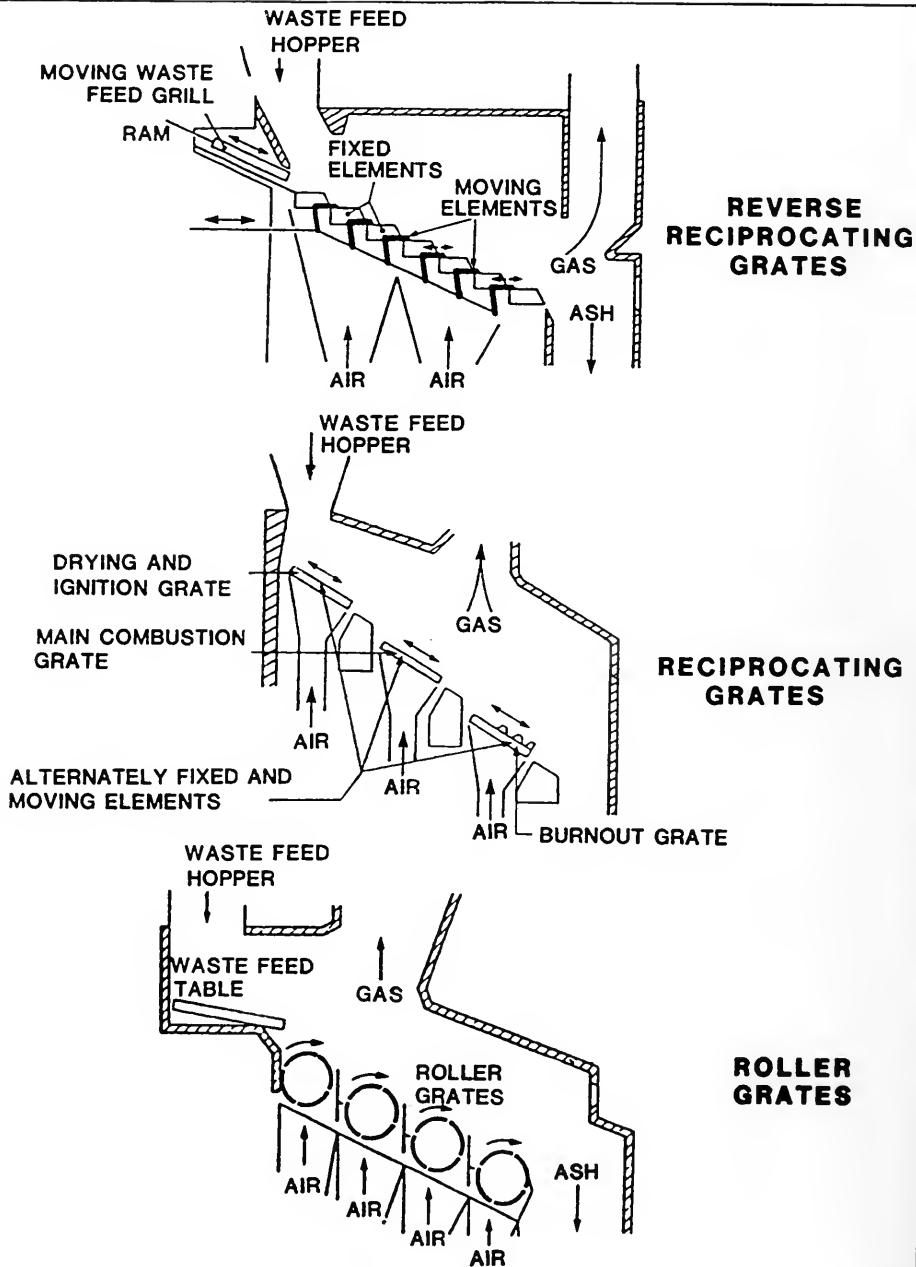
Figure 4-15

**TYPICAL MOVING GRATE DESIGNS
FOR CENTRAL WASTE INCINERATORS**

Application. Central waste incineration systems are used primarily for refuse incineration. The practice has been more prevalent and more long-standing in Europe than in North America. In Canada, mass burning of municipal refuse in central waste incinerators is being carried out at central incineration facilities at Quebec City, St. David, and Montreal, Quebec; Toronto and Hamilton, Ontario.

Development Status. Mass burning of refuse in central incineration facilities is a commercially demonstrated technology. Due to the relatively large size of such units and unique features of each system with respect to waste handling, energy recovery, etc., these facilities are normally designed and built to meet each customer's specific needs.

Operating Practice. Operating temperatures in mass-burning central waste incinerators are normally maintained in the order of 1000°C (1832°F) and refuse residence time on the grate ranges from 20 to 45 minutes. Refractory wall systems normally require 100 to 150% excess air to maintain operating temperatures, whereas waterwall systems require only about 80% excess air. This offers the advantages of a smaller furnace volume and reduced NO_x formation with the latter system, due to the lower airflow. Waterwalls extract heat from the burning waste. Without waterwalls, where the furnace chamber is lined with refractory, the furnace temperature must be controlled by the injection of cool air. In refractory or waterwall furnaces the maximum temperatures should be below 1100°C (2010°F), the temperature at which slagging problems will begin to occur. Table 4-11 lists temperatures at which ash from a typical refuse composition will begin to deform.

Table 4-11
Ash Fusion Temperatures

	Reducing Atmosphere °C (°F)		Oxidizing Atmosphere °C (°F)	
Refuse				
Initial				
Deformation	1030-1130	(1880-2060)	1110-1150	(2030-2100)
Softening	1200-1300	(2190-2370)	1240-1320	(2260-2410)
Fluid	1320-1400	(2400-2560)	1360-1480	(2480-2700)
Coal				
Initial				
Deformation	1060-1100	(1940-2010)	1100-1240	(2020-2270)
Softening	1080-1200	(1980-2200)	1160-1340	(2120-2450)
Fluid	1230-1430	(2250-2600)	1310-1430	(2390-2610)

SOURCE: C.R. Brunner, INCINERATION SYSTEMS: Selection and Design, Van Nostrand Reinhold, 1984.

Underfire air is provided beneath the grates to prevent overheating of the grate system and to supply part of the waste combustion air requirement. Air is also provided above the grates (overfire air) to burn off the products of combustion of the waste and to properly direct flue gas flow within the furnace. Underfire air will comprise from 40% to 60% of the air flow to the furnace, with the over-fire air flow inserting the balance of the air required for incineration.

White goods (stoves, refrigerators, etc.) must be removed from the waste feed. With some systems there is limited ability to handle waste tires, and they must be removed or distributed throughout the daily feed.

The mass burn waterwall furnace is designed to generate steam (or hot water) as well as to incinerate waste. Its design must include provisions to minimize boiler tube corrosion.

There are two types of corrosion mechanisms normally associated with waste burning facilities. One is dew point

and the other is high temperature corrosion. Dew point corrosion occurs when the flue gas stream is reduced in temperature to less than 150°C (302°F). Refuse will contain plastics which, in turn, have a chloride component. In the presence of water vapour, which is always present when burning refuse, the chloride will convert to hydrogen chloride gas. When the gas temperature drops below 150°C (302°F), the hydrogen chloride will begin to condense to a liquid, hydrochloric acid which will produce severe corrosion to steel and other metallic surfaces.

High temperature corrosion of steel occurs when hydrogen chloride is present in the flue gas. At temperatures in excess of 370°C (700°F), ferric chloride will form; this compound is friable, i.e., it will form a series of flakes on the steel surface and the surface will "waste" away. As the temperature increases, this type of corrosion will increase significantly.

To reduce dew point corrosion, the exiting flue gas must never be allowed to drop too low in temperature. This is particularly important when an economizer or an air pre-heater is used to try to extract relatively low level heat from the flue gas.

Control of high temperature corrosion is more difficult. By generating steam at a temperature less than 370°C (700°F), the incidence of high temperature corrosion will be greatly reduced (the temperature of the steel boiler tubes is essentially equal to the temperature of the generated steam). The concentration of hydrogen chloride in flue gas is highest just above the grate. To further reduce the corrosion potential of the flue gas, the lower section of waterwall is normally coated with a refractory material with heat conduction properties, such as carbide brick or cement.

When superheated steam is desired, with temperatures in excess of 370°C (700°F), superheater sections should be placed as far as possible from the burning waste, downstream or immediately upstream of the boiler convection section. By the time the flue gas reaches this area of the incinerator, there should have been sufficient mixing by virtue of the turbulent upstream conditions to reduce the occurrence of concentrated pockets of hydrogen chloride. The hydrogen chloride should be fairly evenly distributed through the gas stream, resulting in a relatively low concentration.

Guideline. Central waste incinerators should meet all the aspects of Polices 01-01 and 01-03 as well as the other aspects discussed in Section 4.1.2. It should be noted that the calculation of residence time for these units must be determined by an overall design review.

4.2.2   Semi-Suspension Incineration

Equipment Description. Semi-suspension incineration differs from mass burning in that the waste is pretreated to produce a finer, more homogeneous material, commonly referred to as refuse-derived-fuel or RDF. The pretreatment steps normally include shredding and ferrous metal recovery by magnetic separation, and can include air classification for removal of other non-combustible material (e.g., non-ferrous metal and glass).

The RDF is blown into the furnace through a pneumatic charging system. Primary combustion (of approximately 70% of the waste's combustible content) occurs in suspension. Ash and unburned material drop onto a travelling grate where final burnout occurs. The grate discharges the ash to a hopper for removal to final disposal.

The high degree of turbulence in the furnace contributes to high ash carryover in the flue gas stream, necessitating the installation of higher efficiency particulate removal equipment with this type of incinerator than with mass burn units.

Application. Semi-suspension burning is suitable for the destruction of RDF as well as other materials requiring agitation, or turbulence, for effective combustion (e.g. powdered carbon, sawdust, etc.). It also permits the reclamation of recyclable materials. In Ontario, a semi-suspension incineration system for RDF is located in the City of Hamilton (SWARU).

Development Status. Although semi-suspension incineration systems are commercially available, they have not gained the widespread acceptance that mass-burning systems currently enjoy, largely due to the additional complexity and cost associated with waste preparation. They do, however, allow the reclamation of salvageable materials from the waste stream, which has been recognized by the Provincial and Federal governments to be a desirable activity.

Operating Practice. These systems require waste pre-processing which, at a minimum, includes shredders and magnetic separators (see Section 3.1.4). Although the heating value of the RDF generated by these processes can be 20% higher than the specific heating value of Municipal Solid Waste (MSW), production of this fuel requires a significant investment in capital equipment and high operating costs. Likewise, system reliability is generally lower than mass burn systems because of the greater amount of process equipment.

Guideline. Semi-suspension incinerators should meet all the aspects of Policy 01-01 and 01-03 as well as the other

aspects discussed in Section 4.1.2. It should be noted that the calculation of residence times for these units is particularly complex and must be determined by an overall design review.

4.2.3   Rotary Kiln Incineration

Equipment Description. The rotary kiln is the most flexible and versatile of the incinerators in common use today. As shown in Figure 4-16, it is a horizontal, refractory-lined structure that rotates about its horizontal axis. Waste is fed from one end and, through the action of the rotating chamber, moves toward the other end of the kiln. Burners for startup and provision of a supplementary source of heat can be mounted on either end of the kiln. The kiln is sized and operated so that by the time the waste material reaches the end of the kiln, it has burned out to an ash that falls into a hopper for removal and disposal.

The kiln is mounted at a slight angle to the horizontal, which is referred to as its rake. By varying the rake and the speed of rotation, the waste retention time within the unit can be varied.

Afterburner sections are required to ensure complete burnout of the off-gases.

Application. The rotary kiln system is highly versatile as it is capable of burning solids, sludges, liquids, and gases. Solids are typically ram-fed or dropped by conveyor onto the kiln hearth, while sludges, liquids, and gases are injected through nozzles located in the front or rear face of the kiln or in the afterburner. They are particularly attractive for the destruction of toxic or hazardous wastes due to their ability to operate at temperatures in

Figure 4-16
ROTARY KILN
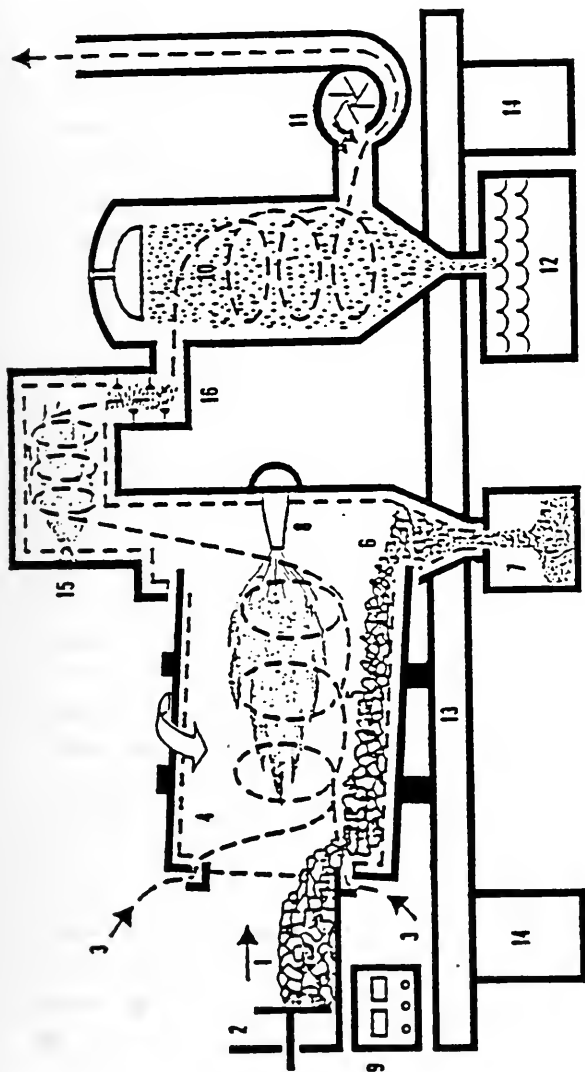
1 Waste to incinerator
2 Auto-cycle feeding system:
  feed hopper, pneumatic feeder, slide gates
3 Combustion air in
4 Refractory-lined, rotating cylinder
5 Tumble-burning action
6 Incombustible ash
7 Ash bin
8 Auto-control Burner Package:
  programmed pilot burner

9 Self-compensating instrumentation-controls
10 Wet-Scrubber Package:
  stainless steel, corrosion-free wet scrubber:
  gas quench
11 Exhaust fan and stack
12 Recycle water, fly-ash sludge collector
13 Support frame
14 Support piers
15 Afterburner chamber
16 Precooler

4-63

excess of 1400°C (2550°F) when fitted with an after-
burner.

Development Status. Rotary kiln incinerators are commer-
cially available in diameters of approximately 1 m and
greater, and have even been constructed as portable,
trailer-mounted units. They have been used by industry,
municipalities, and the military to destroy combustible
liquid, solid, and gaseous wastes. The 3M Company in
London, for instance, is installing a rotary kiln inciner-
ator to dispose of solid and gaseous wastes from its
manufacturing processes.

Operating Practice. The length to diameter ratio for
rotary kilns varies from 2:1 to 10:1. They are usually
mounted at a rake of less than 2 to 3% with a variable
rotational speed normally in the range of 0.25 - 1.5 rpm.

Residence time of solids and sludges is a function of kiln
dimensions, rake, and rotational speed, and is varied with
the type of waste being incinerated. Liquids are normally
fired in suspension. Residence time can range from
seconds for liquids and gases to hours for solids. Excess
air of approximately 100% of the stoichiometric require-
ment is normally required to assure effective incinera-
tion, although some manufacturers have designed kilns for
operation at substoichiometric conditions.

Similarly, combustion temperatures vary according to the
waste characteristics. Temperatures within the kiln are
generally limited to less than 1000°C (1832°F), but after-
burners may operate as hot as 1650°C (3000°F). Kilns have
been developed that are maintained at temperatures in
excess of 1300°C (2370°F) to allow a pool of molten slag
to form. These slagging kilns are used when charging a

metal drum or when the waste has a significant inorganic content.

Generally the temperature in the kiln itself is maintained high enough to release volatiles from the waste. Destruction of these volatiles normally is assured in the afterburner. Rotary kiln systems are applicable to solid, liquid, and gaseous waste; however, solid waste must generally be sized to fit within the kiln charging system.

Wastes containing salts are generally not applicable for destruction in a conventional rotary kiln system. Salts will likely be molten at incinerator temperatures, forming a cake or severe slagging where system temperatures drop (in the air emission control train, for instance) below the salt melting temperature. Slagging kilns can be used for wastes containing salts.

In many instances, placing drums of waste directly into a kiln has led to problems of rapid burning or explosions. Even when the drum is cut and quartered, waste adjacent to the drum shell can heat up faster than exposed waste, creating the potential for a conflagration.

Kiln seals present design problems. The kiln seal must fit tight against the moving kiln surface which is uneven and is not necessarily turning true. In addition to this erosive service, the seal must withstand high temperatures radiating from the kiln interior. The kiln seal design should be carefully evaluated for optimal service.

Guideline. Rotary Kiln incinerators. Should always be run at a negative pressure (draft) to prevent external leakage of hot flue gas, as well:

° A rotary kiln used for waste disposal should include provisions for adjustment of rake.

° In addition, the kiln drive should be infinitely
  variable throughout its range.

4.2.4   Biomedical Waste Incineration and Cremators

Volume 2 of this criteria document discusses biomedical
waste incineration in detail, and Volume 3 addresses crem-
ator equipment.

Equipment Description. Three types of incinerators have
been used for the incineration of biomedical waste:

° Multiple chamber
° Controlled air
° Rotary kiln

A cremator is a double chamber incinerator into which is
charged a casket and its contents.

Additional Guideline for Biomedical Waste Incinerators.
The incinerator must be designed to prevent leakage of
liquids that may be contained in the waste. All feed sys-
tems shall be sloped toward the opening of the incinera-
tor. Provisions should be included within the incinerator
system for disinfecting the hopper sides and the charging
containers. The maximum heat release rate should be
400 000 kJ/h/(h-m^3) [12,000 Btu/(hr-ft^3)] in the primary
chamber and 836 000 kJ/(h-m^3) [25,000 Btu/(hr-ft^3)] in the
secondary chamber. A solid hearth should be provided to
hold the charged waste, and the hearth burning rate should
be no greater than 68.5 kg/(hr-m^2) [14 lb/(hr-ft^2)]. The
temperature of the primary chamber should be maintained in
the range of 400°C to 760°C (750°F to 1400°F). At least
two burners should be provided for incinerators rated at
100 kg/h (220 lb/hr) or greater.

<u>Additional Guidelines for Cremators</u>. The primary chamber
should be maintained at a minimum temperature of 800°C
for at least 30 minutes during the last part of the cycle
to ensure complete calcination and sterilization.

4.2.5   Multiple Hearth Systems

<u>Equipment Description</u>. This is a vertical cylindrical
structure, refractory-lined, with a series of refractory
hearths positioned one beneath the other, as shown in
Figure 4-17.

The centre shaft, which is hollow to allow the passage of
cooling air through it, rotates within the incinerator at
approximately one revolution per minute carrying the
rabble arms with it sweeping waste across the hearths.
The waste is rabbled from the edge of one hearth to its
centre, and drops to the next hearth where it is rabbled
to the outside of that hearth, and so on. Alternate
hearths have large centre openings or outside drop holes
through which the waste falls.

The furnace is particularly well suited to the combustion
of sludge, which is dried on the top hearths and starts to
burn toward the centre of the furnace. It burns out to
ash at the bottom of the furnace where it is discharged.

<u>Application</u>. Multiple hearth incinerators are designed to
burn wastes with low heating value such as sewage sludge
and other high-moisture-content wastes. Its design
includes drying as well as burning sections. Materials
with less moisture content, such as coal or solid waste,
will start to burn too high in the furnace. There would
be insufficient residual time in these cases for effective
burnout.
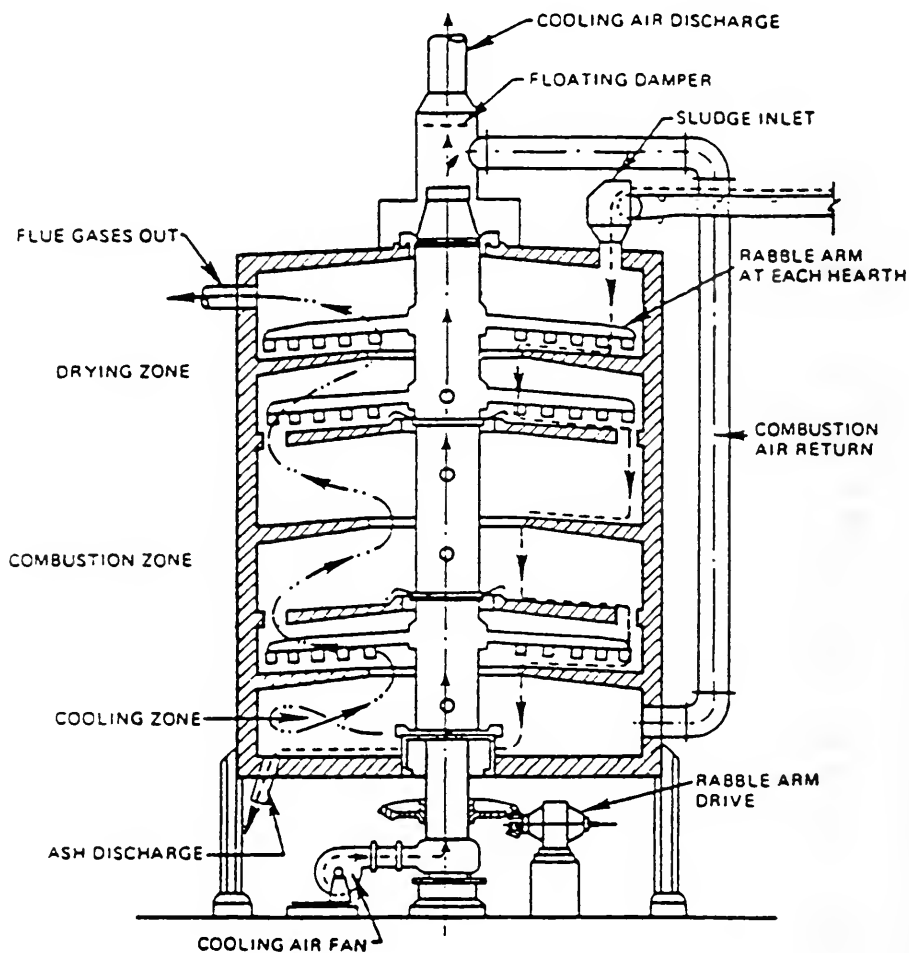
Figure 4-17

MULTIPLE HEARTH INCINERATOR

This incinerator system is relatively complex with fans,
burners, shaft speed, and feed charging all within the
operator's control, and all affecting combustion efficien-
cy and burnout. Particular attention must be paid to
operator training in the proper control of these various
equipment items and parameters.

Development Status. This is the most prevalent incinera-
tion system for sewage sludge destruction in North
America. Several multiple hearth incinerators are being
used to burn sewage sludge in Toronto, Ontario.

Operating Practice. Multiple hearth furnaces range from 2
to 8 m (6.6 to 26.2 ft) in diameter and from 4 to 23 m (13
to 76 ft) in height. The number of hearths is dependent
upon the waste feed and processing requirements, but gen-
erally varies between 5 and 12 hearths. Waste retention
time is controlled by the rabble tooth pattern and the
rotational speed of the central shaft.

The upper hearths of the furnace comprise the drying zone
where moisture is evaporated from the sludge. Flue gas
exits this upper zone of the incinerator at 430°C to 650°C
(806°F to 1202°F). In the centre hearths, the combustion
zone, temperatures are normally in the 760°C to 980°C
(1400°F to 1796°F) range. Cooling air exiting the top of
the centre shaft is approximately 90°C to 230°C (194°F to
446°F), and is often recirculated to the furnace as pre-
heated combustion air.

Where sludge contains grease or other volatile components,
an afterburner may be required for effective burnout,
i.e., elimination of smoke and odour. The maximum off-gas
temperature from the incinerator is below 700°C (1291°F).
If higher temperatures are required, a separate after-
burner must be provided. The afterburner can be an

expanded top hearth or it can be provided as a separate
piece of equipment.

Excess air of 100-125% must be provided to ensure complete
burnout of the sludge to ash. Since approximately 20% of
the ash can be entrained in the flue gas, extensive gas-
cleaning equipment must be provided for its capture (see
Chapter 6 for a discussion of air emissions control equip-
ment).

This incinerator will handle sludges in the range of 50 to
85% moisture. It is generally not applicable to the
incineration of solid materials.

The multiple hearth furnace is a flexible piece of equip-
ment. There is a limitation in the sludge consistency
that it can process (generally from 15 to 50% solids
content) but the nature of the sludge is not necessarily
limiting as with, for instance, the fluid bed furnace.
Another feature of the multiple hearth furnace is that it
has a relatively constant fuel use curve, i.e., the use of
fuel is directly proportional to the amount of sludge
burned, its moisture and combustible content, and its
heating value. If the sludge feed is doubled, the fuel
required to incinerate the sludge is doubled. This is not
necessarily true with other types of incinerator systems,
such as the fluid bed incinerator.

Ash exits this system dry from beneath the furnace. It
can be collected and disposed of dry, or it can be dropped
into a wet hopper, mixed with water, and pumped to a
lagoon for dewatering and ultimate disposal.

Feeding a multiple hearth is relatively simple. Feed can
be dropped onto the top hearth by gravity. It can also be
deposited on the top hearth or a lower hearth by means of

a screw conveyor. Attempts to feed sludge to a multiple
hearth furnace pneumatically have met with failure. This
system necessarily injects air into the furnace in strong
discrete bursts which makes maintenance of constant furn-
ace draft difficult, if not impossible.

There are a number of disadvantages in the use of this
equipment. Generally, the multiple hearth furnace cannot
accommodate a temperature in excess of 1000°C (1830°F)
without damage. If higher temperatures are required, an
afterburner must be provided, which represents higher
capital costs and higher operating (fuel) costs.

It is virtually impossible to maintain heat in a multiple
hearth furnace without firing supplemental fuel. This
furnace, as noted above, has many areas of leakage and,
therefore, heat cannot be effectively maintained within
the units as in, for example, a fluid bed furnace.

Fuel or gas can be used as supplemental fuel. Generally
solid fuels, such as coal or wood chips, should not be
placed on a hearth and used as supplemental fuel. They
are relatively dry and will start burning on the top
hearth, encouraging premature release of volatiles from
the waste stream and inadequate burnout can result.

Guideline. Sludge or other wastes deposited on the hearth
of a multiple hearth furnace should have a solids content
of 15 to 40% for proper movement and rabbling through the
furnace. The temperature above at least two hearths
should be maintained at approximately 870°C (1600°F) at
all times when burning sludge cake. The off-gas tempera-
ture can range from 425°C to 760°C (800°F to 1400°F).

Generally, grease (scum) should not be added to sludge
feed. If grease is to be incinerated in the multiple

hearth furnace it should be added at a lower hearth (a burning hearth) through a separate nozzle(s). Grease will volatilize easily and introducing it too high in the furnace where the temperatures may be below 760°C (1400°F) will not provide effective burnout.

Air emissions control equipment should be provided to reduce particulate emissions.

Dry solids or solid fuels should not be fed to a multiple hearth furnace. Exceptions may be considered if the solids are added beneath the drying zone in the burning zone of the furnace.

The oxygen content of the flue gas exiting the furnace should be continuously measured at the breeching leaving the top hearth. A sample should be continuously extracted from the gas stream, passed through a water bath to clean the sample and to reduce its moisture content, and then measured for oxygen content. The oxygen content should be in the range of 6 to 10% by volume.

In general, industrial waste liquids and gases should not be introduced into the multiple hearth incinerator itself. They should be fired in a separate afterburner immediately downsteam of the incinerator.

The multiple hearth furnace should always be run at a negative pressure (draft) to prevent external leakage of hot flue gas. If a separate afterburner is needed and if an emergency discharge stack is provided, the stack should be located downstream of the afterburner.

4.2.6   Fluidized Bed Incinerators

Equipment Description. As illustrated in Figure 4-18, the
fluid bed furnace is a cylindrical, refractory-lined shell
with a porous plate elevated to support a bed of inert
material. Preheated air is introduced through the wind-
box, beneath the plate, and passes upwards through open-
ings in the plate, fluidizing the sand bed.

Waste is fed into or on top of the bed, which is normally
maintained at a temperature of 760°C to 870°C (1400°F to
1600°F) by auxiliary burners located either above or below
the bed. Moisture in the waste flashes to steam almost
instantaneously. The organics are burned within the bed
or in the freeboard zone above the bed. Ash will either
exit the incinerator in the exhaust gas or it will build
up within the bed. Virtually all of the residual ash when
burning sewage sludge is elutriated from the bed and
entrained in the flue gas stream. This heavy fly ash
loading must be removed in downstream particulate removal
equipment.

Application. Fluid bed furnaces have been used for com-
bustion of many materials, including coal, coke, wood, oil
sands, and several other fuels. In incineration applica-
tions, fluidized bed systems have been used principally
for the combustion of sludges, particularly sewage sludge.
A prime requisite for the successful combustion of solid
waste is that it be adequately prepared by shredding and
sorting.

The only application of fluid bed incineration to solid
waste in North America is in Minnesota where solid waste
and sludge have been incinerated in the same unit. This
installation has experienced many technical problems.

Hot gas in
1500°F.

REACTOR

Fluidized
sand bed

WINDBOX

Hot air
1000°F.

AIR
PREHEATER

Gas out
To scrubber

Cool
air
in

BLOWER
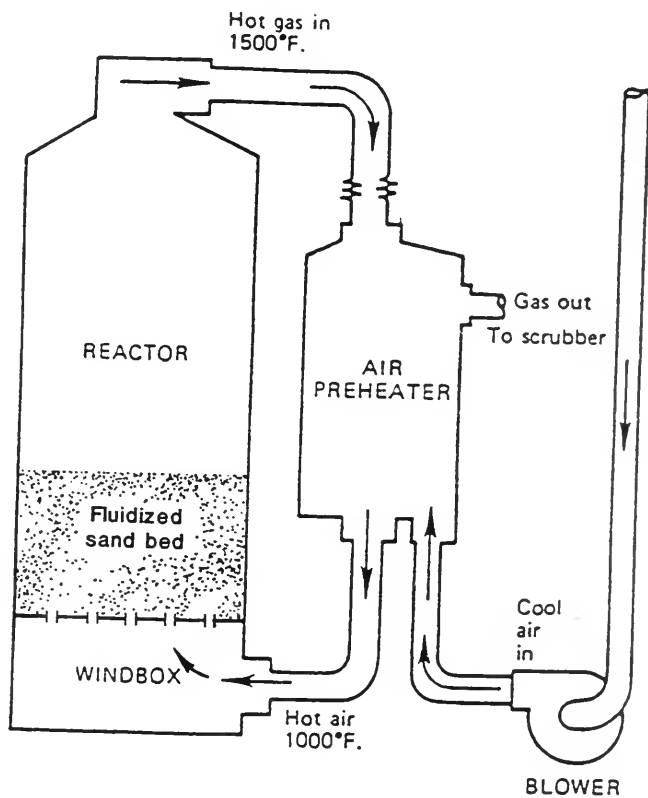
Figure 4-18
FLUIDIZED BED SYSTEM

The presence of heavy, non-combustible materials in the
waste may cause the bed volume to increase with time,
necessitating that it be tapped to prevent excessive
agglomeration.

Development Status. Fluidized bed technology has been
employed in several industries for many years. The first
fluid bed used for incineration of sewage sludge was in
1962. Since that time it has been gaining popularity in
North America. In Canada, fluidized bed incinerators are
used at Pickering and Mississauga, Ontario, to dispose of
sewage sludge.

Operating Practice. The bed material is most commonly
silica sand, but may also be comprised of limestone,
alumina, or ceramic material. The bed expands from 30 to
60% in volume when fluidized with air at a velocity of
approximately 0.5 to 1.5 m/s (1.5 to 4.5 ft/sec).

Excess air requirements are low, usually only from 40 to
60%. Residence time is determined by bed depth, freeboard
above the bed, and the fluidizing velocity, and is select-
ed based on the characteristics of the waste being
burned.

The fluid bed furnace system is compact, of airtight con-
struction, and with most manufacturers, is maintained as a
positive pressure system. By maintaining the entire sys-
tem under positive pressure, the furnace must be designed
to be airtight. This feature is useful in applications
where the furnace is called upon to operate on a non-con-
tinuous basis. If the furnace is to operate five days per
week, for instance, its airtight construction allows it to
be sealed fairly effectively. Dampers on its inlet and
outlet will hold in its heat and the refractory and sand
within the unit provide significant thermal inertia. As a

result of its construction the fluid bed furnace after a shutdown will lose as little as 5°C (9°F) per hour. It can be shut down on a Friday evening and will require only a few hours of heat-up on a Monday morning to be available for waste feeding.

The fluid bed furnace has few moving parts. Its major area of maintenance is the recuperator, or gas-to-air tube-in-shell heat exchanger that is usually provided with this equipment. This equipment is sensitive to temperature and is generally limited to a sustained operating temperature of 900°C (1650°F). Above this temperature severe corrosion will occur, reducing the heat exchanger tube wall dimension to the point of weakness and subsequent failure. Oxygen present in the flue gas will de-carburize carbon steel at temperatures in excess of 900°C (1650°F), producing the indicated corrosive effect. Other incinerator heat exchanger designs, particularly insertion type units such as the ones of European manufacture, use an intermediate heat exchange medium such as heated oil, hot water or steam, and the effect of the high incinerator off-gas temperatures is not as significant as with the tube-in-shell exchanger.

An internal water spray system is often employed in fluid bed systems to help protect the heat exchanger from temperature excursions. Water is automatically injected into the freeboard when the heat exchanger inlet temperature is above a pre-set figure, perhaps 870°C (1600°F).

A fluid bed furnace requires a minimum amount of air to maintain bed fluidization, regardless of the waste feed. The fluidizing air requirement is based on the furnace rating. When the bed is operating at a feed below the design point, approximately the same air quantity is required as is required at design to maintain fluidiza-

tion. This results in a unit that may have good fuel
consumption at its design point, but has a relatively high
fuel consumption at lesser feeds.

While ash from a fluid bed furnace normally exits with the
flue gas, the ash from some materials when burned will not
be airborne but will build up in the bed, requiring
periodic bed tapping. Provisions should be included with-
in the fluid bed system to accommodate excessive bed
build-up. `

Where all of the ash does exit with the flue gas (plus
some of the bed sand), the air emissions control system
must be designed to remove this load from the gas stream.
As a result, high energy scrubbing systems with higher
pressure drops than other sludge incineration systems are
required.

Feeding of a fluid bed furnace requires particular atten-
tion. Except for certain European furnaces in which nega-
tive pressure is maintained in the freeboard and where
waste can be dropped into the furnace by gravity, most
fluid bed furnaces are under positive pressure. Waste
must be forced into the furnace, and gravity feed cannot
be used. Positive displacement pumps are normally used
for feeding fluid bed furnaces. Hard piping should be
used from the pumps to the furnace and a purge system
should be included to help prevent caking of the piping
when not in use.

A major issue associated with a fluid bed furnace is its
ability to handle a wide variety of waste streams. It is
sensitive to waste composition. Certain wastes, particu-
larly those containing clays, inorganics (salts), or high
quantities of lime, will tend to seize the bed, preventing
fluidization. Test burns on materials that have not pre-

viously been fired in a fluid bed furnace must be perform-
ed to determine the bed reaction to those particular
materials. If bed seizure does occur, bed additives may
be available to help eliminate this problem by changing
the physical properties of the waste feed. If not, a
fluid bed unit may not be the one to use. A related issue
is agglomeration. Waste materials may build up on indiv-
idual sand particles within the bed. With changes in
operation (such as maintaining a higher bed residence
time) this could be controlled. If not addressed, agglom-
eration could result in bed seizure.

It has been found that natural gas will not necessarily
burn well within a fluid bed. It will tend to pass
vertically through the bed without mixing within the sand.
It can be fired in a windbox beneath the sand bed, howe-
ver, without this concern.

Guideline. Sludge, liquids, and prepared solid waste can
be fed directly to the bed of the fluid bed reactor.
Sludges with a moisture content in excess of 80% and aque-
ous liquids with high water contents can be fed in the top
of the furnace at the furnace ceiling rather than into the
bed. Top injection tends to reduce the bed area otherwise
required for sludge moisture evaporation.

The temperature within the bed should be maintained at
approximately 760°C (1400°F) for organic sludges. The use
of sludges or other wastes containing inorganic materials
should be subject to a test burn before injecting into a
fluid bed furnace.

The freeboard should be maintained in the range of 760°C
to 870°C (1400°F to 1600°F). This temperature should
never be allowed to exceed 870°C (1600°F) when a heat
exchanger is used, unless the heat exchanger is specifi-

cally designed for operation at a higher gas inlet temperature. Water sprays should be provided at the ceiling of the furnace for cooling the gas stream if its temperature approaches 870°C (1600°F).

Gaseous waste or fuel should not be injected into the bed. It can be fired in the windbox.

The oxygen content of the flue gas exiting the furnace should be continuously measured at the breeching leaving the furnace upsteam of the recuperator (if one is provided). A sample should be continuously extracted from the gas stream, passed through a water bath to clean the sample and to reduce its moisture content, and then measured for oxygen content. The oxygen content should be in the range of 4 to 8% by volume, on a dry basis.

In general, industrial waste liquids and gases should not be introduced into a fluid bed incinerator if they require a temperature in excess of 870°C (1600°F) for destruction. The air heater normally provided with these systems cannot withstand greater than 870°C (1600°F) inlet gas temperature. An afterburner is normally not provided for a fluid bed incinerator system.

4.2.7   Liquid Injection Furnaces

Equipment Description. For purposes of incinerator design, a material is considered a liquid if it can be pumped to a burner, atomized, and fired in suspension. Liquid injection incinerators are either horizontally or vertically oriented, cylindrical, refractory-lined chambers fitted with nozzles firing axially or tangentially into the furnace. Several types of atomizing nozzles and burners are used to achieve vapourization of the waste and efficient air/fuel mixing, including fixed orifice

nozzles, rotary cup burners, two-fluid burners, and sonic nozzles.

Primary combustion air is normally injected into the waste nozzle with compressed air or steam to promote atomization, while secondary air is introduced downstream of the nozzles to increase turbulence, cool the refractory wall, and control combustion. A typical liquid waste incinerator is illustrated in Figure 4-19.

Applications. Liquid injection incinerators can be used to dispose of almost any combustible liquid waste, including lubrication oils, paints, solvents, and pesticides. With appropriate nozzle design, liquids with kinematic viscosities of up to 1.62×10^{-4} m^2/s (750 SSU) can be fired in suspension.

Development Status. A wide variety of liquid injection incinerators are marketed today, and these represent probably the most common incinerator type for hazardous waste disposal. In Ontario, Tricil Limited in Corunna and Dow Chemical Canada Inc. in Sarnia operate liquid injection incinerators for destruction of liquid industrial wastes. In the United States, ship-mounted, liquid injection incinerators are seeking permits for test burns for disposal of hazardous materials at sea.

Operating Practice. Liquid injection furnaces typically require 15-30% excess air and operate at retention times in the range of 0.5 to 2 seconds. Operating temperatures vary from 650°C to 1650°C (1200°F to 3000°F), but are normally around 870°C (1600°F), depending on waste destruction characteristics.

Liquid waste can be injected within the flame front if its heating value is high enough to add to the net heating
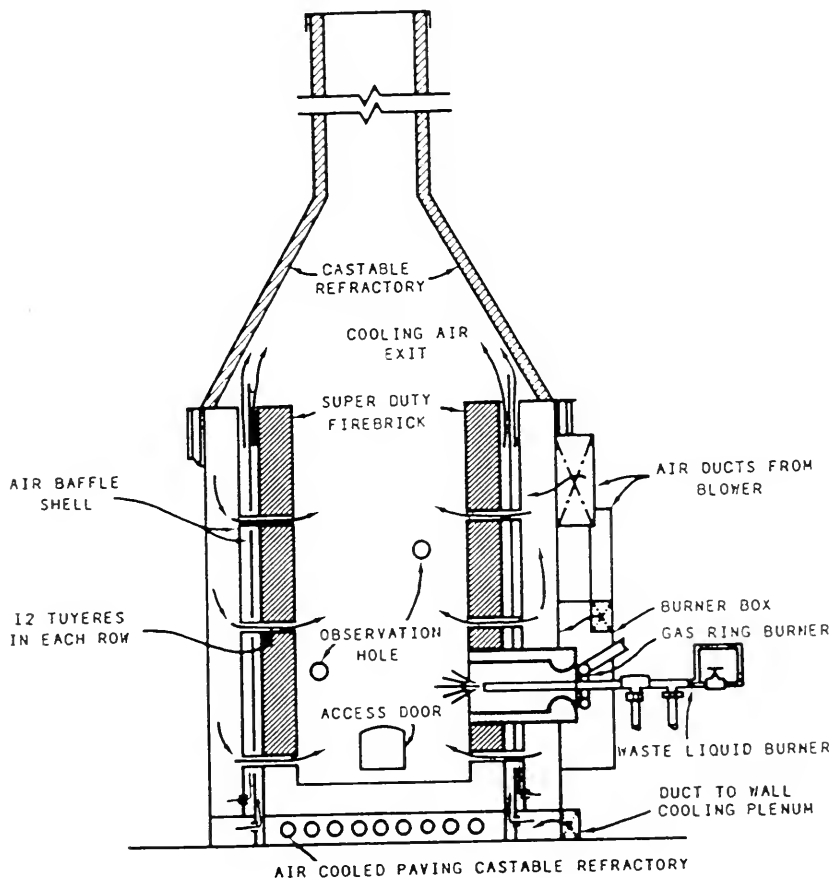
Figure 4-19
LIQUID WASTE INCINERATOR

value of the flame (i.e., greater than approximately 11 600 kJ/kg [4987 Btu/lb]). Aqueous or other low heating value waste is normally injected outside the flame envelope.

Conventional liquid waste incinerators may not be able to handle wastes containing inorganic salts. Salts will be molten at temperatures in the range of 760°C to 870°C (1400°F to 1600°F) and can condense downstream of the firing chamber to form slag. Specialty liquid waste incinerators have been developed specifically for inciner-ation of salt-laden wastes; they maintain salt in a fluid state and quench the molten salt in a water bath.

The types of nozzle used will often have a significant impact on the design of the furnace, and can be chosen to prevent flame impingement. Following is a discussion of nozzle types used with liquid waste streams.

Mechanical Atomizing Nozzles. These are the most common types of burner nozzles in current use. Fuel is pumped into the nozzle at pressures of 515-1030 kPa (75-150 psig) through a small fixed-orifice discharge. The fuel is given a strong cyclonic or whirling velocity before it is released through the orifice. Combustion air is provided around the periphery of the conical spray of fuel produc-ed. The combination of combustion air introduced tangen-tially into the burner and the action of the swirling fuel produce effective atomization. Normal turndown ratios are in the range of 2.5:1 to 3.5:1. By utilizing a return flow line for fuel oil, the turndown ratio can be increas-ed to as high as 10:1. A major disadvantage of this type of burner/nozzle is its susceptibility to erosion and pluggage from solids components of the fluid stream. Flames tend to be short, bushy, or low velocity, and this results in slower combustion, requiring relatively large

combustion chamber volumes. This burner is applicable for fluids with relatively low kinematic viscosity, under .22 x 10^{-4} m^2/s (100 SSU).

Rotary Cup Burners. Atomization is provided by throwing fuel centrifugally from a rotating cup or plate. Oil is thrown from the lip of the cup in the form of conical sheets which break up into droplets by the effect of surface tension. No air is mixed with fuel prior to atomization. Instead, it is introduced through an annular space around the rotary cup. Normally a common motor drives the oil pump, rotating cup, and combustion air blower. The liquid pressure required for this burner is relatively low, since automization is a function of cup rotation and combustion air injection, not fuel pressure. This low pressure requirement and the relatively large openings within the burner fuel path allow passage of fluids with relatively high solids contents, as high as 20% by weight. They have a turndown ratio of approximately 5:1 and can fire liquids with kinematic viscosity up to .65 x 10^{-4} m^2/s (300 SSU). Rotary cup burners are sensitive to combustion air flow adjustment. Insufficient air flow will result in fuel impingement on furnace walls, while excessive combustion air will cause a flame-out.

External Low-Pressure Air-Atomizing Burners. The major portion of the combustion air requirement is provided at 7-35 kPa (1-5 psig) near the burner tip. Air is injected externally to the fuel nozzle and is directed to the liquid stream to produce high turbulence and effective atomization. The liquid pressure necessary for operation is only enough for positive delivery, normally less than 10 kPa (1? psig). Secondary combustion air is provided around the periphery of the atomized liquid mixture. The flame is relatively short because of the high amount of air provided at the burner (atomization and secondary

combustion air). The short flame allows design of smaller combustion chambers. These burners normally operate with liquids in the range of .43-3.24 m²/s (200-1500 SSU) and can handle solids concentrations in the liquid of up to 30%. A small quantity of the air flow passes around the fuel discharge to aid in optimization of the fuel flow pattern.

External High-Pressure Two-Fluid Burners. The atomizing fluid, air or steam (or nitrogen or other gas), impinges the fuel stream at high velocity to generate small particles that encourage quick vapourization and effective atomization of tars and other heavy liquids. The required atomization pressure varies from 200 to 1030 kPa (30 to 150 psig). Turndown is in the range of 3:1 to 4:1. The flame produced is relatively long, requiring appropriately constructed combustion chambers. The fuel viscosity normally handled by these burners ranges from .3 to 10.8 m²/s (150 to 5000 SSU) for either air or steam atomization. A solids content of up to 70% can be accommodated by these burners.

Internal Mix Nozzles. Air or steam is introduced within the nozzle to provide impingement of atomization fluid on the fuel stream prior to spraying. Atomization air is provided at pressures less than 200 kPa (30 psig) and steam is normally introduced at 620-1030 kPa (90-105 psig). The turndown ratio for this type burner is from 3:1 to 4:1. These nozzles cannot tolerate a signficant solids content and can handle only low-viscosity fuels, under .22 m²/s (100 SSU). This burner is used for clean, low-viscosity liquids. Its advantage is in its low cost compared to other burners.

Sonic Nozzles. These nozzles utilize a compressed gas such as air or steam to create high frequency sound waves

which are directed at the fuel stream. This acoustic energy is transferred to the liquid stream and creates an atomizing force, breaking the stream into minute particles. The fuel nozzle diameter is relatively large, allowing passage of solid particulate streams such as slurries and sludges with high particulate content. Little fuel pressurization is required. The spray pattern is not well defined, with finely atomized, uniformly distributed droplets travelling at low velocities. These nozzles are difficult to adjust, have low turndown, and generate an extremely high noise level during operation.

Guideline. The design of the furnace should include provisions to prevent flame impingement on a furnace wall. With flame from either the waste or the supplemental fuel impinging on a wall, the full heating value of the fuel is not realized. The resultant carbonaceous build-up on the wall prevents normal gas flow within the furnace from "washing" the surface and hot spots will develop. In addition, this build-up will eventually result in corrosion of the refractory and increased refractory maintenance.

Liquid waste streams containing in excess of 50 ppmv inorganics may not be appropriate candidates for conventional liquid waste incinerators. Specialty incinerators may have to be used which are designed specifically for this duty.

4.2.8   Gas Incineration

There are basically two methods of gaseous waste destruction, direct flame and catalytic incineration. Direct flame combustion includes flares, fume incinerators, gas combustors, and afterburners. This is the most common method of gas incineration. Catalytic incineration uses

catalysts to reduce the temperature required for waste destruction.

4.2.8.1 Direct Flame Incineration

Equipment Description. Direct flame incineration requires bringing a waste gas to an appropriate temperature and holding it there long enough to oxidize the organics to carbon dioxide and water. Flaring is the simplest means of disposing of relatively large quantities of waste gas with combustible components. The gas is ignited and discharged to the atmosphere without heat recovery. The process is particularly suited to the disposal of intermittent gas discharges.

As illustrated in Figure 4-20, a flare is basically a stack discharging a combustible gas to the atmosphere. A pilot flame at the end of the stack ignites the gas, the combustion of which is supported by the surrounding atmosphere. Steam is frequently introduced into the flame to generate turbulence and promote mixing with the surrounding air, to aid in cracking complex molecules, and to help oxidize carbon.

Fume incinerators and gas combustors are chambers equipped with supplemental fuel burners that provide the temperature and residence time necessary for a more controlled combustion of gaseous waste materials. They may be either horizontal or vertical in orientation, although vertical units are not usually suited to heat recovery.

Fume incinerators can be equipped with some means of heat recovery. The hot exhaust gases may be used to preheat the incoming combustion air or waste gas or to heat a stream for external use.
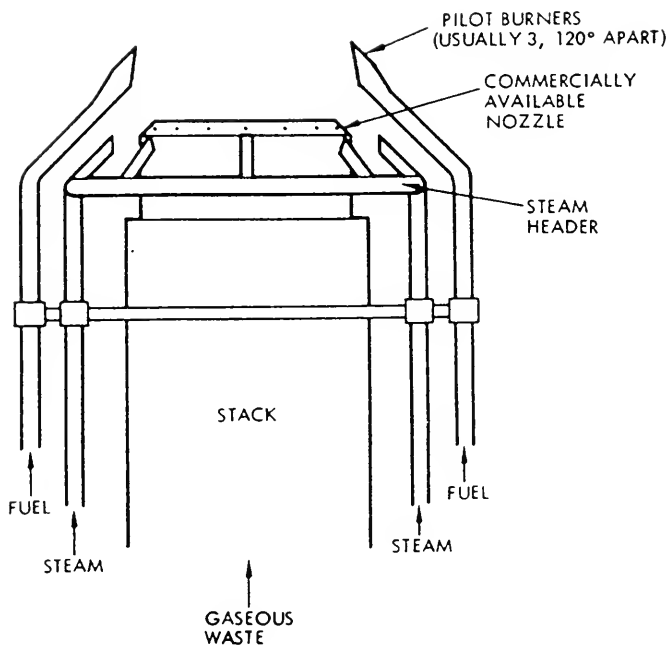
Figure 4-20
TYPICAL FLARE

Application. Direct flame incineration is best applied to waste gas streams rich in combustible constituents. Probably the most common application of flares is the combustion of waste gases and vent gases from petroleum refining operations. Fume incinerators have been successfully applied to control smoke and solvent emissions from surface coating operations, odourous emissions from food facilities, as well as combustible fumes from a wide variety of industries such as printing, food processing, and chemical processing.

Development Status. Numerous types of flare and direct flame incineration equipment are commercially available for gas combustion.

Operating Practice. Combustion temperatures developed in flare systems normally range from 1100°C to 1400°C (2010°F to 2550°F). However, residence time and air/fuel mix are relatively uncontrolled, frequently resulting in incomplete combustion of the waste gas.

Combustion chamber temperatures in fume incinerators vary from 430°C to 820°C (806°F to 1508°F), depending on the waste constituent, with residence time ranging from 0.5 to 2 seconds.

4.2.8.2 Catalytic Incineration

Equipment Description. Catalytic incinerators are used to destroy the organic components of a gas stream at lower temperatures than that required by direct combustion, thus effecting significant energy savings for wastes containing low concentrations of combustibles.

The waste gas is normally preheated with fired burners and is then passed over a catalyst bed where the oxidation

reactions proceed. The catalyst is normally deposited on an inert material with a high surface area.

At the appropriate temperature and residence time with sufficient oxygen present, 85 to 95% destruction of hydrocarbons can be achieved with catalytic incinerators.

A typical catalytic incinerator is illustrated in Figure 4-21.

Application. Catalytic incineration is most applicable to the destruction of gaseous wastes with low concentrations of combustibles. The waste stream must be free of particulates and several other contaminants (e.g. heavy metals, phosphates, arsenic compounds, halogens, sulphur compounds, alumina and silica dusts, iron oxides, and silicones) which can foul the catalyst materials. Table 4-12 lists a number of these catalyst inhibitors and their effect on the process.

Development Status. Although commercially available, catalytic incinerators are not widely used for waste gas destruction.

Operating Practice. Catalytic incinerators normally operate at temperatures below 600°C (1110°F)and residence times of approximately one second. The catalyst section is normally sized to provide a pressure drop no greater than 1 kPa (4 in W.C.). It should not be used unless the gas stream constituents are consistent in analysis and contain neither particulate matter, halogens, nor other contaminants listed above.
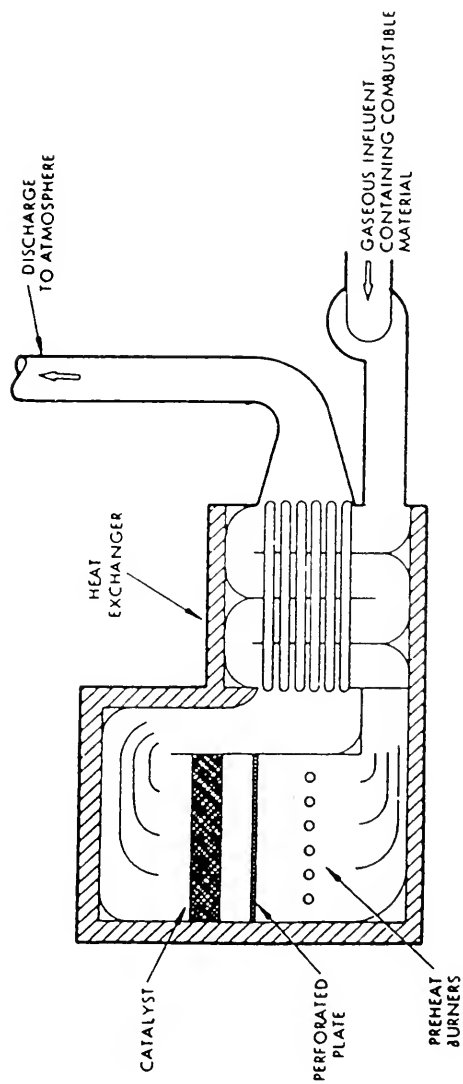
Figure 4-21
CATALYTIC INCINERATOR

Labels within figure:
- DISCHARGE TO ATMOSPHERE
- GASEOUS INFLUENT CONTAINING COMBUSTIBLE MATERIAL
- HEAT EXCHANGER
- CATALYST
- PERFORATED PLATE
- PREHEAT BURNERS

Table 4-12
Catalyst Inhibitors

Type of Inhibitor	Effect
Fast-Acting Inhibitors Phosphorous, Bismuth, Lead, Arsenic, Antimony, Mercury	Irreversible reduction of catalyst activity at rate dependent on concentration and temperature.
Slow-Acting Inhibitors Iron, Tin, Silicon	Irreversible reduction of catalyst activity. Higher concentrations than those of fast-acting catalyst inhibitors may be tolerated.
Reversible Inhibitors Sulphur, Halogens, Zinc	Reversible surface coating of catalyst active area. Removed by increasing catalyst temperature.
Surface Eroders and Maskers Inert Particulate	Surface coating of catalyst active area. Also errosion of catalyst surface at rate dependent on particulate size, grain loading, and gas stream velocity.

4.2.8.3 Guideline

Flares or direct flame incinerators can be used with gases above the upper explosive limit (UEL) or below the lower explosive limit (LEL). Catalytic incinerators operate most efficiently when the gas stream concentration is no more than 25% of the LEL. The LEL is the lowest concentration of a gas in air that will sustain combustion. The UEL is that concentration above which there is insufficient air present to sustain combustion. Table 4-13 lists LEL and UEL values for common compounds.

Supplemental fuel for flares is required when the gas heating value is less than 5600 kJ/Nm^3 (150 Btu/SCF).

Table 4-13
Combustibility Characteristics of Pure Gases and Vapours in Air

Gas or Vapour	Lower Limit, % by Volume	Upper Limit, % by Volume
Acetaldehyde	4.0	57.0
Acetone	2.5	12.8
Acetylene	2.5	80.0
Allyl alcohol	2.5	-
Ammonia	15.5	26.6
Amyl acetate	1.0	7.5
Amylene	1.6	7.7
Benzene (bensol)	1.3	6.8
Benzlyl chloride	1.1	-
Butene	1.8	8.4
Butyl acetate	1.4	15.0
Butyl alcohol	1.7	-
Butyl cellosolve	-	-
Carbon disulfide	1.2	50.0
Carbon monoxide	12.5	74.2
Chlorobenzene	1.3	7.1
Cottonseed oil	-	-
Cresol, m- or p-	1.1	-
Crotonaldehyde	2.1	15.5
Cyclohexane	1.3	8.4
Cyclohexanone	1.1	-
Cyclopropane	2.4	10.5
Cymene	0.7	-
Dichlorobenzene	2.2	9.2
Dichloroethylene (1,2)	9.7	12.8
Diethyl selenide	2.5	-
Dimethyl formamide	2.2	-
Dioxane	2.0	22.2
Ethane	3.1	15.5
Ether (diethyl)	1.8	36.5
Ethyl acetate	2.2	11.5
Ethyl alcohol	3.3	19.0
Ethyl bromide	6.7	11.3
Ethyl cellosolve	2.6	15.7
Ethyl chloride	4.0	14.8
Ethyl ether	1.9	48.0
Ethyl lactate	1.5	-
Ethylene	2.7	28.6
Ethylene dichloride	6.2	15.9
Ethyl formate	2.7	16.5
Ethyl nitrite	3.0	50.0
Ethylene oxide	3.0	80.0
Furfural	2.1	-
Gasoline (variable)	1.4-1.5	7.4-7.6
Heptane	1.0	6.0
Hexane	1.2	6.9

Table 4-13 (cont'd)

Gas or Vapour	Lower Limit, % by Volume	Upper Limit, % by Volume
Hydrogen cyanide	5.6	40.0
Hydrogen	4.0	74.2
Hydrogen sulfide	4.3	45.5
Illuminating gas (coal gas)	5.3	33.0
Isobutyl alcohol	1.7	-
Isopentane	1.3	-
Isopropyl acetate	1.8	7.8
Isopropyl alcohol	2.0	-
Kerosene	0.7	5.0
Linseed oil	-	-
Methane	5.0	15.0
Methyl acetate	3.1	15.5
Methyl alcohol	6.7	36.5
Methyl bromide	13.5	14.5
Methyl butyl ketone	1.2	8.0
Methyl chloride	8.2	18.7
Methyl cyclohexane	1.1	-
Methyl ether	3.4	18.0
Methyl ethyl ether	2.0	10.1
Methyl ethyl ketone	1.8	9.5
Methyl formate	5.0	22.7
Methyl propyl ketone	1.5	8.2
Mineral spirits No. 10	0.8	-
Naphthalene	0.9	-
Nitrobenzene	1.8	-
Nitroethane	4.0	-
Nitromethane	7.3	-
Noane	0.83	2.9
Octane	0.95	3.2
Paraldehyde	1.3	-
Paraffin oil	-	-
Pentane	1.4	7.8
Propane	2.1	10.1
Propyl acetate	1.8	8.0
Propyl alcohol	2.1	13.5
Propylene	2.0	11.1
Propylene dichloride	3.4	14.5
Propylene oxide	2.0	22.0
Piridine	1.8	12.4
Rosin oil	-	-
Toluene (toluol)	1.3	7.0
Turpentine	0.8	-
Vinyl ether	1.7	27.0
Vinyl chloride	4.0	21.7
Water gas (variable)	6.0	6.0
Xylene (xylol)	1.0	6.0

Note: - Indicates not determined

Radiation from flares should be controlled to less than
34 000 kJ/(m²-h) [3000 Btu/(ft²-hr)] for equipment, 5000
kJ/(m²-h) [440 Btu/(ft²-hr)] for personnel on a continuous
basis and 17 000 kJ/(m²-h) [1500 Btu/(ft²-hr)] for person-
nel on an intermittent basis. Provisions should be
included for noise control in flare design.

Catalytic incinerators should be designed for a maximum
particulate discharge to the atmosphere of 115 µg/Nm³ (.05
gr/SCF). The gas stream entering the catalyst shall have
a minimum temperature of 315°C (600°F) and a maximum
inhibitor concentration (see Table 4-12) of 25 ppmv.

4.2.9   Incineration Systems Summary

Table 4-14 summarizes the qualitative features of each of
the systems noted previously.

4.3   SPECIAL TOPICS

Combustion systems have been in use for several years
burning wastes for energy and material recovery. Specific
examples of these activities are:

°   Firing spent pulping liquors in alkaline sulphate
     (kraft) and acid sulphite pulping to recover heat and
     chemicals in the manufacture of paper and wood cellu-
     lose products

°   Combustion of waste oils in industrial boilers for
     recovery of heat and power generation

°   The use of spent solvents and oils as fuel in the
     production of cement and lightweight ceramic aggre-
     gates

Table 4-14
Incineration System Summary

Incinerator Type	Waste Feed				Feed Preparation	Agitation of Waste	Hazardous Waste	Biomedical Waste	Ash Discharge		Supplemental Fuel			Excess Air Required	Wastewater Discharge	Particulate Emissions
	Solids	Liquids	Sludge	Gaseous					Wet	Dry	Liquid	Gaseous	Solid			
Multiple Chamber	Yes	Limited	Limited	Limited	Limited	Limited	Limited	Yes	Yes	Yes	Yes	Yes	Yes	High	None	High
Pyrolysis	Yes	Limited	Yes	Limited	High	None	Limited	No	Yes	No	Yes	Yes	Yes	None	Yes	High
Controlled Air	Yes	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Yes	No	Yes	Yes	No	Low	Ash pit	Moderate
Mass Burn	Yes	No	Limited	No	None	Limited	No	No	Yes	No	Yes	Yes	Yes	Moderate	Ash pit	Moderate
Semi-suspension	Yes	No	No	No	High	High	No	No	Yes	No	Yes	Yes	Yes	Moderate	Ash pit	Moderate
Rotary Kiln/Afterburner	Yes	Yes	Yes	Yes	Limited	High	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High	Yes	Moderate
Multiple Hearth	Limited	Limited	Yes	Limited	Limited	High	Limited	Limited	Yes	Yes	Yes	Yes	No	High	Yes	Moderate
Fluidized Bed	Limited	Yes	Yes	Limited	High	High	Yes	No	Yes	No	Yes	Limited	Yes	Low	Yes	Moderate
Liquid Injection	No	Yes	No	Limited	Limited	N/A	Yes	No	Yes	No	Yes	Yes	No	Low	None	Low
Direct Flame	No	No	No	Yes	None	N/A	Yes	N/A	N/A	N/A	Yes	Yes	Yes	Low	None	Low
Catalytic	No	No	No	Yes	None	N/A	Yes	N/A	N/A	N/A	Yes	Yes	No	Low	None	Low

N/A: Not applicable

4.3.1   Spent Pulping Liquor Recovery Boilers

In alkaline (kraft) pulping of wood to produce paper and
other cellulose products, a solution of sodium sulphide
and sodium hydroxide is used to dissolve lignin and other
soluble organic compounds from the cellulose fiber used to
make paper. The spent "black liquor" from this alkaline
digestion process contains sodium sulphate, sodium carbon-
ate, lignin, and other organic materials dissolved from
the wood. Oxidation of black liquor is extensively used
to assist in odour control.

After concentration by multiple-effect evaporation, the
black liquor is fired in a specially designed "recovery
boiler." The ratio of primary to total air is carefully
controlled to maintain a reducing (oxygen deficient)
atmosphere in the furnace bed (to convert sulphate to
sulphide) while maintaining an oxidizing atmosphere in the
upper zone of the furnace. Excess air added above the
furnace bed assures combustion of volatile organics and
oxidation of gaseous sulphide compounds to sulphur diox-
ide. As the organic material is burned off at approxi-
mately 840°C to 850°C (1540°F to 1560°F) in the char-bed,
the remaining inorganic sodium salts, principally sodium
carbonate and sodium sulphide, form a smelt.

To recover chemicals for reuse in makeup of new cooking
liquor, the smelt is dissolved and recausticized with lime
to convert sodium carbonate to sodium hydroxide. Steam
from the recovery boiler is used for evaporation of the
spent black liquor and drying in the paper machines.

If oxidation above the furnace bed is not complete, prin-
cipal air emissions include particulate resulting from
sublimation of sodium salts and odours produced by reduced

sulphur compounds including hydrogen sulphide, mercaptans, and other organic sulphides.

Corrective odour control measures require analysis of specific situations; no single solution found satisfactory at one location generally can be transferred without modification to another location. In general, conversion from a direct-contact evaporator to an indirect-contact evaporator and maintenance of excess oxygen in the recovery boiler reduces odour problems. Mills with direct-contact evaporators can operate at low emission rates of total reduced sulphur (TRS) if the flue gas is controlled to maintain 2 to 3% oxygen. Using a caustic scrubber in the flue gas emissions control system would also result in very low TRS emissions.

In acid sulphite pulping where chemicals are recovered, wood chips are "cooked" with a sodium, magnesium, or ammonium sulphite or bisulphite cooking liquor. The spent "red liquor" from this digestion process contains sulphate salts and dissolved organics that bind the cellulose fibers together in wood. The red liquor is concentrated by multi-effect or vapour recompression evaporation and normally burned in an oxidizing recovery boiler. In the combustion process sodium and magnesium form metal oxides and sulphur compounds are converted to sulphur dioxide. Where ammonium ion is used as the base salt, combustion converts ammonia to nitrogen gas and water.

The metal oxides are recovered as particulate from the flue gas and dissolved in water to produce sodium or magnesium hydroxide. Sulphur dioxide in the flue gas is absorbed with water to produce sulphurous acid. Combining the recovered metal (sodium or magnesium) hydroxide with sulphurous acid then produces new sodium or magnesium sulphite/bisulphite cooking acid. This completes the chemi-

cal recovery process. As with alkaline pulping, steam from the recovery boiler is used for spent liquor evaporation and paper drying.

Temperature within the boiler depends on the complex heat and mass transfer reactions that occur. Complete combustion of the organic solids is essential for heat output and chemical recovery. This means that the spent-liquor feed rate and residence time in the high-temperature zone of the furnace must be balanced.

Air emissions include unrecovered particulate metal oxides and sulphur dioxide. Venturi scrubbers utilizing absorbent liquors have out-performed packed towers in the removal of SO_2 from stack gases. Final SO_2 concentrations from the stack should be less than 250 mg/l.

4.3.2   Burning of Wastes in Industrial Boilers

Generally, liquid wastes, as opposed to solid or sludge wastes, have been fired in power boilers. Destruction of waste components in excess of 99% of their initial concentration occurs in industrial boilers when temperatures are maintained in excess of 980°C (1800°F) and a minimum residence time of 1.5 seconds for most nonhalogenated materials and 1200°C (2200°F) and 2-second residence time for halogenated waste. The boiler should have good mixing in the combustion chamber and a good control system.

When burning wastes in boilers, blending and operation plans should be developed to address:

°   Additional gas cleaning requirements necessary to handle the ash content of waste fuels

o   Control of hydrogen chloride or other acid gas result-
     ing from the burning of waste fuels

o   Increased maintenance of boilers and air-cleaning
     equipment resulting from the use of waste fuels

o   Installation of ash discharge equipment at the bottom
     of the boiler to catch and discharge accumulated bot-
     tom ash

In general, criteria for waste firing in a boiler include
the following:

     Gross waste heating value   >18,000 kJ/kg, as fired

     Ash content   <1.5%, as fired

     Chloride content of the
     organic matter   >0.5%, as fired

     Minimum operation temperature 870°C (1600°F)

4.3.3   Burning of Wastes in Cement Kilns

Cement kilns and light aggregate kilns operate at maximum
temperatures between 1100°C and 1400°C (2010°F and 2550°F)
with gas phase residence times of 40 to 120 seconds in the
kiln. Particulate discharges are normally controlled by
baghouses or electrostatic precipitators. Afterburners
are normally not used. The controls for monitoring temp-
erature, air flows, feed rates, and excess oxygen are
typically in place as part of the cement kiln control
process.

Use of these kilns for wastes should address:

°   Additional burner for waste liquid

°   Adequate mixing of the waste in the kiln for proper
    oxidation

°   Any increased requirement to control particulate due
    to additional mixing requirement in the kiln

°   Flow control of waste to the kiln

°   Potential product (clinker) degradation from residual
    ash from the waste stream

Chloride emissions are not expected to be a concern.
Hydrogen chloride reacts with the lime clinker feed to
form calcium and magnesium salt, which would be retained
in the cement solids and would be a comparatively insigni-
ficant component of these solids.

A major concern in waste firing is the location of the
introduction of waste to the kiln. If waste is introduced
at the low-temperature end of the kiln, the temperature is
usually high enough to volatilize the higher combustibles
within the waste stream. These volatiles may pass through
the system uncombusted to the atmosphere and create emis-
sion problems. If introduced at the hot end of the kiln
where cement clinker is discharged, there may be insuffic-
ient residence time for the noncombustibles of the waste
to mix and blend with the clinker, and inferior product
quality may result. Therefore, a separate burner is
required for the waste combustion. The type of waste, its
volatility, and the nature of the production process in
question must be evaluated carefully to determine if a
particular waste can be effectively fired and destroyed.

4.4 DEVELOPING TECHNOLOGIES

There are a number of other technologies that have been developed for the thermal destruction/treatment of hazardous wastes. Following are descriptions of a number of these alternative treatment systems.

4.4.1 Circulating Fluid Bed

In the circulating bed (Figure 4-22), combustible waste is introduced into the bed along with recirculated bed material from the hot cyclone. Both the fresh feed and the recirculating material are fed into the combustion chamber. A high air velocity (4 to 6 m/s) results in carryover of both bed material and the combustible waste, which rise through the reaction zone to the top of the combustion chamber and pass into a hot cyclone. The cyclone separates hot gas from solids, which are reinjected to the combustion chamber via the return seal. The hot flue gases pass to a gas cooler, then to a baghouse filter. Bed material could include alkali substances to capture and retain acid gases (HCl and SO_2).

Tests indicate that efficient combustion can be accomplished over a wide range of operating conditions, as follows:
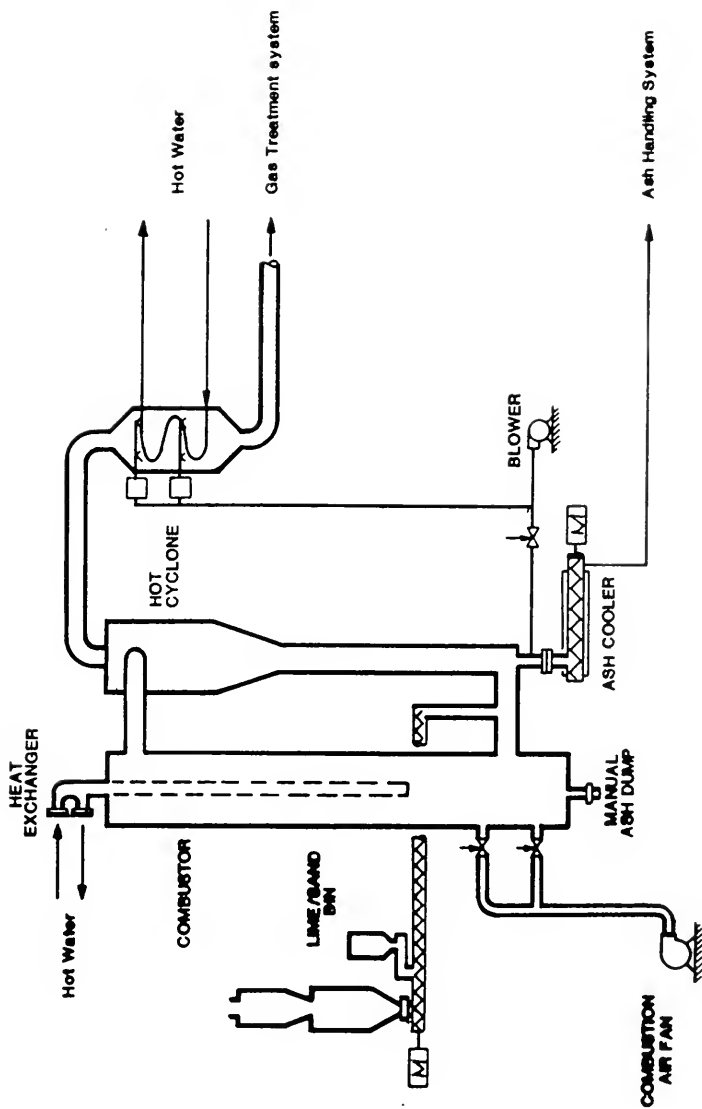
Figure 4-22
CIRCULATING FLUID BED

Temperature	-	780°C to 870°C (1436°F to 1598°F)
Excess Air	-	15% to 100%
Air Velocity	-	0.9 to 6 m/s (3 to 20 ft/s)
Form of Waste Feed	-	Solid, slurry, liquid, sludge
Waste Composition	-	0% to over 90% ash
		0% to over 90% water
		0% to 50% chlorine
		0% to 30% fluorine, sulphur, or sodium

Combinations of these operating conditions have been found to yield over 99.99% waste destruction. The high degree of mixing action in the combustor allows feeds of wide variation in viscosity to be incinerated effectively.

4.4.2   Rotary Reactor

The rotary reactor consists of a hollow, three-compartment cylinder that rotates from 10-30 revolutions per minute. The rotary reactor acts as a fluidized bed with a hot inert medium (e.g., sand) with solid or semi-solid wastes mechanically lifted on internal radial fins and cascaded through the combustion gases in the combustion zone. The solid cascading action provides effective mass transfer and high rates of heat transfer. This results in destruction efficiencies of greater than 99.99% at 870°C (1598°F).

The major features of the rotary reactor are:

° Ability to incinerate wastes with a heat content as low as 4600 kJ/kg (2,000 Btu/lb) as fired without auxiliary fuel

° The use of coal as an auxiliary fuel for wastes with heating values less than approximately 4600 kJ/kg (2,000 Btu/lb)

° Neutralization of acidic combustion gases by the addition of lime to the combustion chamber. This reduces the gas scrubbing requirements and also simplifies the materials of construction.

4.4.3   Molten Salt Incineration

The molten salt process (Figure 4-23) has been developed to dispose of a wide variety of wastes: solids, liquids, and sludges. It is an oxidation and recombinant process whereby wastes are oxidized and/or chemically altered to innocuous substances.

Soluble alkali salts are used as the bed material. A single salt or a mixture of salts can be used. The more common salts in use are sodium chloride (NaCl), sodium sulphate (Na_2SO_4), sodium phosphate (Na_3PO_4), sodium carbonate (Na_2CO_3), and corresponding calcium salts.

The salt bed is heated to fluidization, its temperature a function of the salt material utilized. Waste is prepared before feeding (if solid wastes, by shredding) and is fed directly into the molten salt bed if liquid or sludge. Typical temperatures of the bed are in the range of 700°C to 850°C (1290°F to 1560°F).
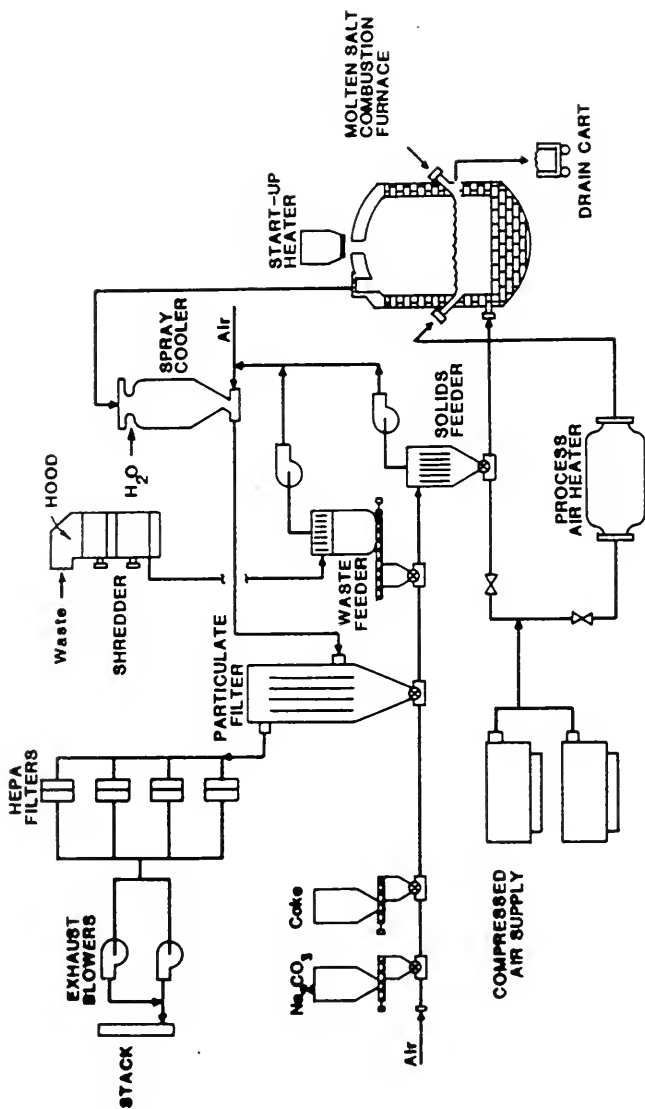
Figure 4-23
MOLTEN SALT INCINERATOR

Waste components dissolve within the melt, producing an off-gas. The off-gas will contain carbon dioxide and moisture (steam), and oxygen and nitrogen from the air supply. It will also contain particulate matter, salt, and other components generated within the melt. After particulate removal, the gas is discharged to the atmosphere.

The volume of the melt increases as waste is added to the system and it must be tapped periodically. Many compounds can be separated from the salt and the salt can be recycled to the incinerator for reuse.

Off-gas is exhausted through a quench or spray cooler where its temperature is reduced below 150°C (302°F). At this temperature the gas can pass through electrostatic or fabric filters for particulate removal prior to discharge through induced draft blowers feeding an exhaust stack. High efficiency particulate air filters (HEPA filters) may or may not be necessary, depending on the particulate loading and size distribution.

Liquid and sludge waste can be taken directly to the incinerator and charged beneath the melt surface. Solid waste is shredded to uniform size and is then transferred to a waste feeder. Shredded solid waste, residue from the particulate filter, fresh salt, and coke is conveyed through a single pipeline to a solids feeder which, in turn, feeds the furnace.

Combustion products from a typical molten salt process are as follows:

Salt: Sodium Carbonate

Oxidizing Agent: Air

Element In Feed	Combustion Product
Carbon	Carbon Dioxide
Hydrogen	Steam
Chlorine, Fluorine	Sodium Chloride, Fluoride
Phosphorus	Sodium Phosphate
Arsenic	Sodium Arsenate
Sulphur Silicon	Sodium Sulphate
Silicon (Glass)	Sodium Silicate
Iron (Stainless Steel)	Iron Oxide
Silver (Photo Film)	Silver Metal

4.4.4   Flash Drying

Flash drying is a system used for disposal of various sludge wastes. Sludge waste is dried and can then be burned or disposed of by another method or within the flash drying system. Its principal elements (note Figure 4-24) are a hot gas heater, sludge mixer, cage mill, cyclone collector, vapour fan, and dry product conveyor.

Wet sludge is blended with a small quantity of dried sludge in the mixer to improve its transportability. This mixed sludge is fed to a windbox on the cage mill where hot gas, from 540°C to 760°C (1004°F to 1400°F) (depending upon the nature of the sludge), contacts the sludge. Moisture begins to evaporate into steam. The mixture of sludge, hot gas, and steam is ground together in the cage mill. The sludge is pneumatically conveyed to a cyclone where separation of dry sludge from gas and moisture vapour occurs by flashing at approximately 150°C (302°F).
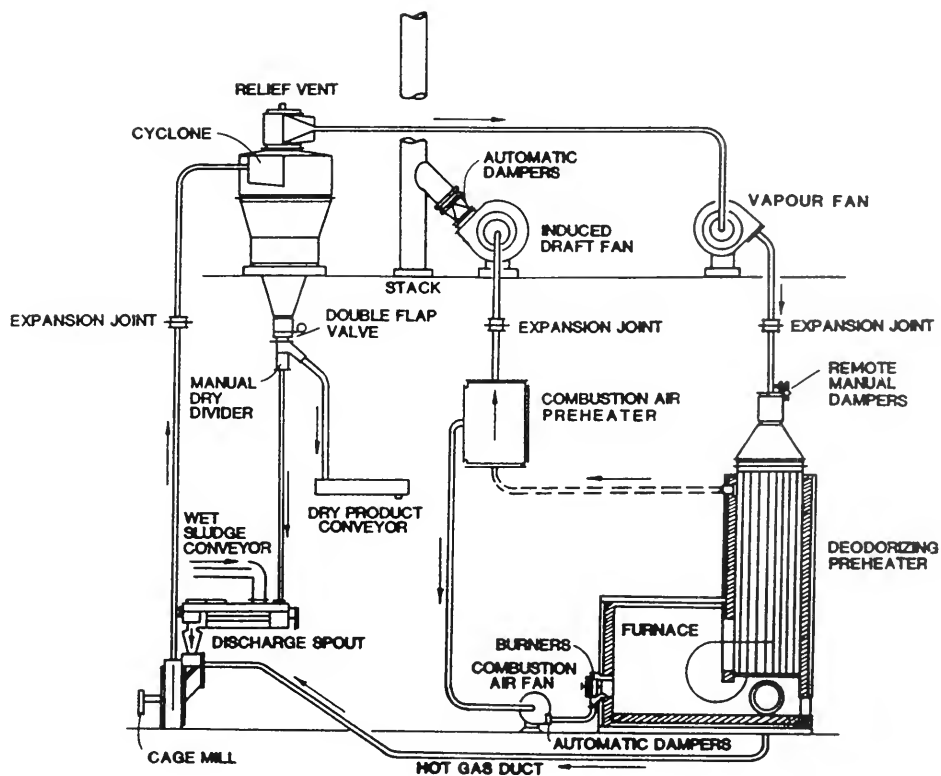
Figure 4-24
FLASH DRYER SYSTEM

A dry sludge (containing 4 to 8% moisture) is discharged
by the dry product conveyor. This material can be burned
to produce the hot gas required for initiation of the pro-
cess. The dry product can be incinerated to produce the
steam required by the process or it can be taken away for
alternate disposal or use. The furnace utilizes conven-
tional fuel for generating hot gas; the dry sludge is
removed from the process as a dry material.

The spent gases from the cyclone must be incinerated prior
to discharge to the atmosphere. In this process a vapour
fan blows these gases from the cyclone to a vertical heat
exchanger (recuperator) within the furnace. The spent gas
picks up heat from the recuperator and is heated further
within the furnace to 760°C (1400°F). At this tempera-
ture, with a residence time in excess of 0.5 seconds, the
odour components will destruct. The hot gas will pass
over tubes in the recuperator, losing some of its heat to
the incoming gas. The gas continues to another heat
exchanger, a preheater, which heats combustion air prior
to its injection into the furnace adjacent to the supple-
mental fuel burner. The spent gas will exit the preheater
and will discharge from the stack at approximately 260°C
(500°F).

4.4.5   The Carver-Greenfield Process

The Carver-Greenfield process (Figure 4-25) is a method of
drying moisture-laden liquid or sludge through heating and
evaporation.

After waste feed is passed through a grinder to give it a
uniform consistency, it is pumped to a fluidizing tank
where an oil is added and mixed with the sludge. The
feed/oil mixture passes through a series of evaporators
where the moisture is evaporated leaving the solids sus-
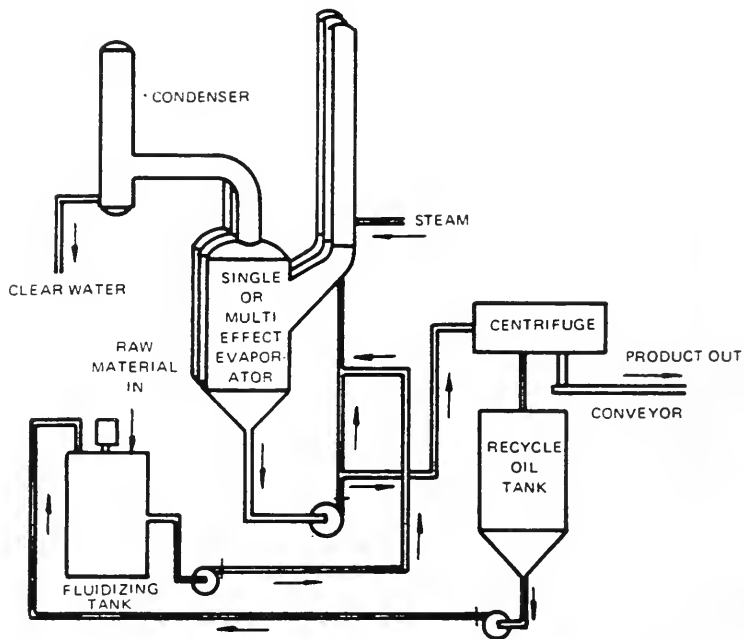
Figure 4-25
CARVER-GREENFIELD PROCESS

pended in the carrier oil. Four stages of evaporation are often used; however, because the number of stages required is a function of feed properties, as few as two stages may be sufficient for some materials.

The feed is pumped through a heat exchanger prior to each stage of evaporation and ultimately is discharged to a centrifuge. The centrifuged solids will normally contain less than 1% of the original oil added to the feed and less than 2% by weight of moisture. The dry solids can be burned to provide steam for the evaporators or, as with flash dryers, they can be disposed of outside the system.

• The balance of the equipment used in this process captures and recovers the carrier oil to allow its reuse.

Off-gases, including spent steam, from this system are normally burned in the steam boiler as combustion air. The atmospheric discharge from this system is the stack from the steam boiler. The only other discharge is the dried product.

4.4.6   High Temperature Fluid Wall Reactor

The High Temperature Fluid Wall (HTFW) reactor (Figure 4-26) consists of a tubular core of porous graphite which is capable of emitting sufficient radiant energy to destroy organic contaminants. The core is completely jacketed and insulated in a gas-tight pressure vessel. Electrodes located in the annular space between the jacket and the core provide the energy required to heat the core to radiant temperatures.

This system has been developed for the destruction of soil-bound organic contaminants. Raw materials are ground to a relatively fine mesh and are dried to a moisture
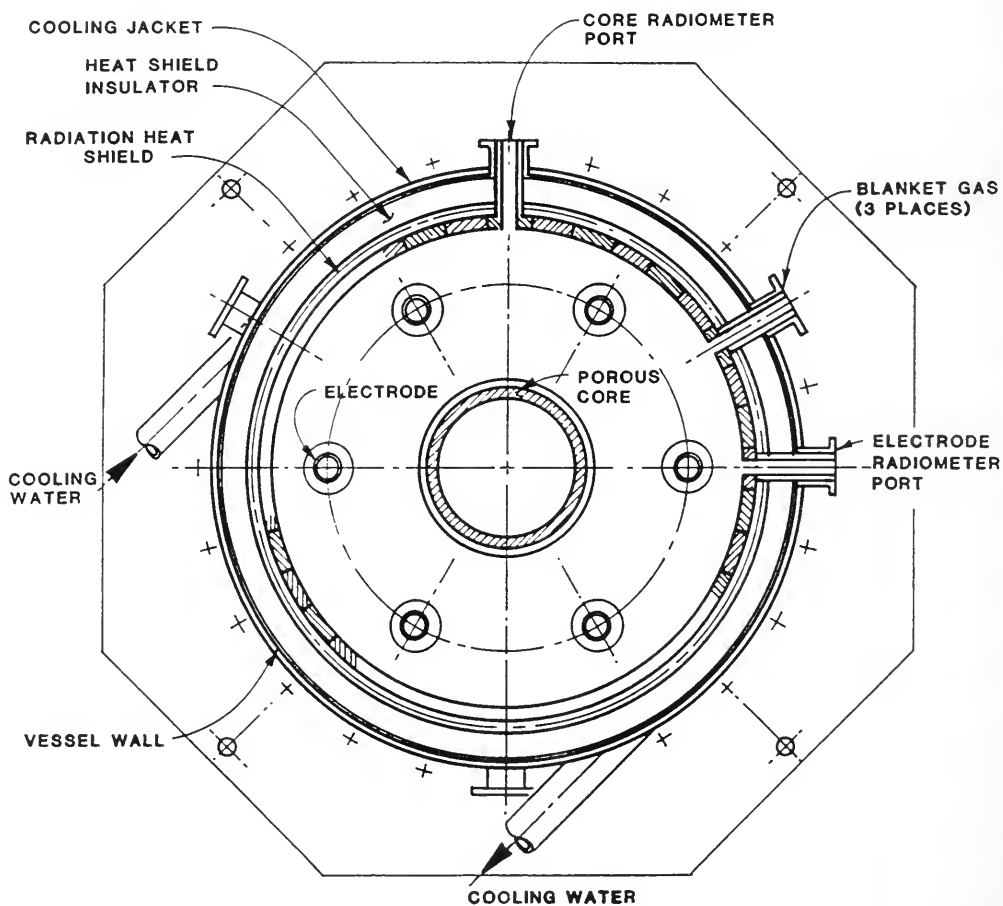
Figure 4-26
HIGH TEMPERATURE FLUID WALL REACTOR

content less than 8%. The material is dropped by gravity
into the reactor feed throat.

The core is heated by the external electrodes and its
inner surface re-radiates the energy into the tubular
space where the materials are introduced. Temperatures in
the range of 2200°C to 2800°C (3990°F to 5070°F) are pro-
duced, causing the organic contaminants to be volatilized.
The advantages of this method of energy transfer are that
the organic contaminants are almost instantaneously heated
and the chemical reactions are greatly accelerated without
heating the entire process stream to the reaction tempera-
ture.

The core and electrodes are insulated within the reactor
jacket by graphite materials. The reactor exhausts to a
water-jacketed heat exchanger. After cooling, the reac-
tion products enter a collection tank. Airborne particu-
late is captured with a cyclone and baghouse.

4.4.7   Wet Air Oxidation

Wet air oxidation is a process whereby a sludge will
release bound water upon application of heat. Sludges
that are colloidal gels, such as organic sludges, are com-
posed of minute particles bound by sheaths that contain
water as well as sludge solids. Upon application of heat,
the sheath will dissolve, releasing the bound water within
the sludge particle. Upon release of bound water, the
sludge solids can be dewatered or further processed.

Thermal conditioning is a low pressure wet air oxidation
process where the end product, thermal-conditioned sludge,
is readily dewaterable. High pressure wet air oxidation
produces a sludge that is not only dewaterable but that
has been oxidized.

Referring to Figure 4-27, raw sludge is first ground to uniform consistency. For thermal conditioning the reactor pressure will be from 1.2 to 1.4 MPa and for high pressure oxidation the reactor pressure can be as high as 8.2 to 16 MPa.

Compressed air is injected into the sludge feed. Air provides turbulence within the sludge stream, increasing heat transfer efficiency through the heat exchanger(s). It is also required for oxidation of malodourous, gaseous compounds released with the release of bound water. High pressure wet air oxidation, however, requires additional air for oxidation of the sludge solids. Depending on the amount of air injected into the sludge and system pressure, the conditioned sludge can be partially oxidized or can be oxidized to a sterile ash.

Steam is injected within the reactor to provide the required reactor pressure and residence time. Temperatures range from 150°C to 340°C (302°F to 644°F), and normal residence time within the reactor is from 10 to 30 minutes.

The hot sludge exiting the reactor passes through one or a series of heat exchangers where most of the available heat is transferred to the entering raw sludge to reduce the total system heating requirements. Raw sludge is pumped through the heat exchanger tubes and the hot conditioned sludge is on the shell side of the heat exchanger.

From the heat exchanger, the conditioned sludge goes to a separator, or storage tank, where a quiescent period is provided. Gases are released and these gases are highly odourous. They are normally incinerated before discharge to the atmosphere.
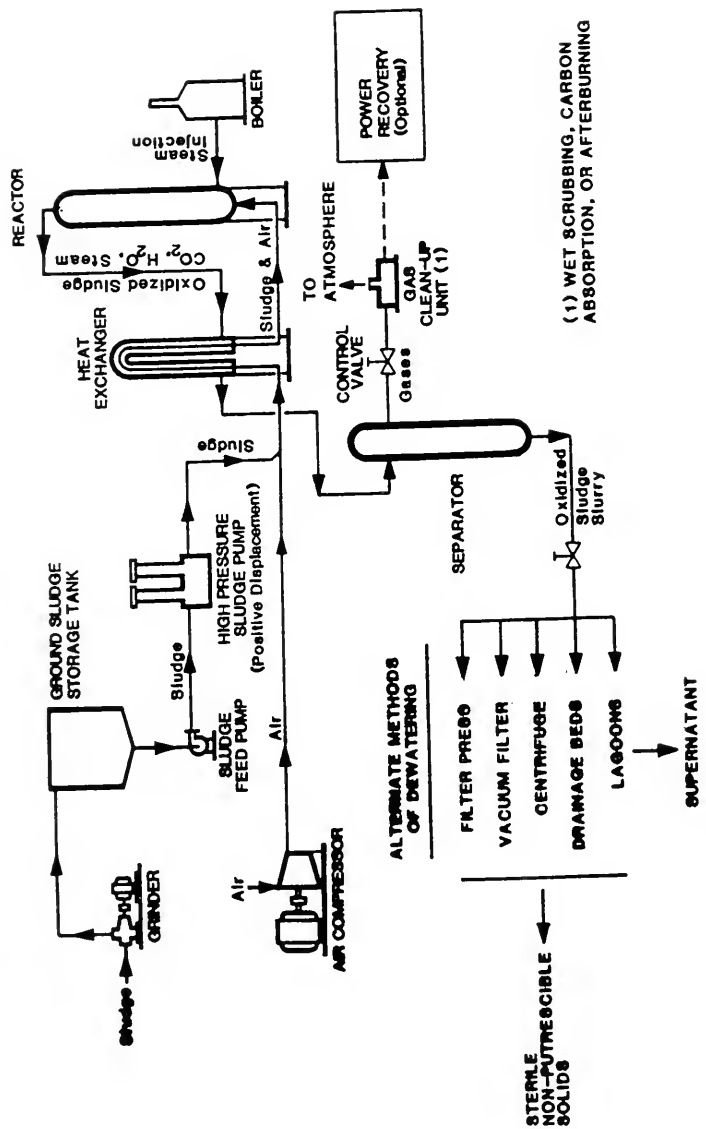
Figure 4-27
WET AIR OXIDATION

4.4.8   Supercritical Fluid Oxidation

This is an experimental system and has not been demon-
strated outside the laboratory.

Supercritical fluid oxidation is basically a high tempera-
ture, high pressure wet oxidation process, as shown in
Figure 4-28. Above the critical temperature, 399°C
(750°F), and pressure, 22.1 MPa of water, organic mater-
ials and gases are completely miscible with water. Organ-
ics, air, and water are brought together in a mixture of
25 MPa and temperatures in excess of 400°C (752°F).
Organic oxidation occurs spontaneously at these condi-
tions. The heat of combustion is released within the
fluid, and it results in a rise in temperature to 590°C to
650°C (1094°F to 1202°F). Under these conditions, organ-
ics are rapidly oxidized with efficiencies that have been
measured in excess of 99.999%.

The waste, as either an aqueous solution or a slurry, is
pressurized and delivered to the oxidizer inlet. It is
heated to supercritical conditions by direct mixing with
recycled reactor effluent. Oxygen is supplied in the form
of compressed air, which is used as the motive fluid in an
eductor to provide recycle of a portion of the reactor
effluent. This inlet mixture is then a homogeneous phase
of air, organics, and supercritical water.

The heat released by combustion of readily oxidized com-
ponents is sufficient to raise the fluid phase to
temperatures at which all organics are oxidized rapidly.
The discharge from the oxidizer is fed to a cyclone. The
solubility of inorganics in supercritical water is
extremely low at the reactor effluent temperatures.
Inorganic salts that are originally present in the feed or
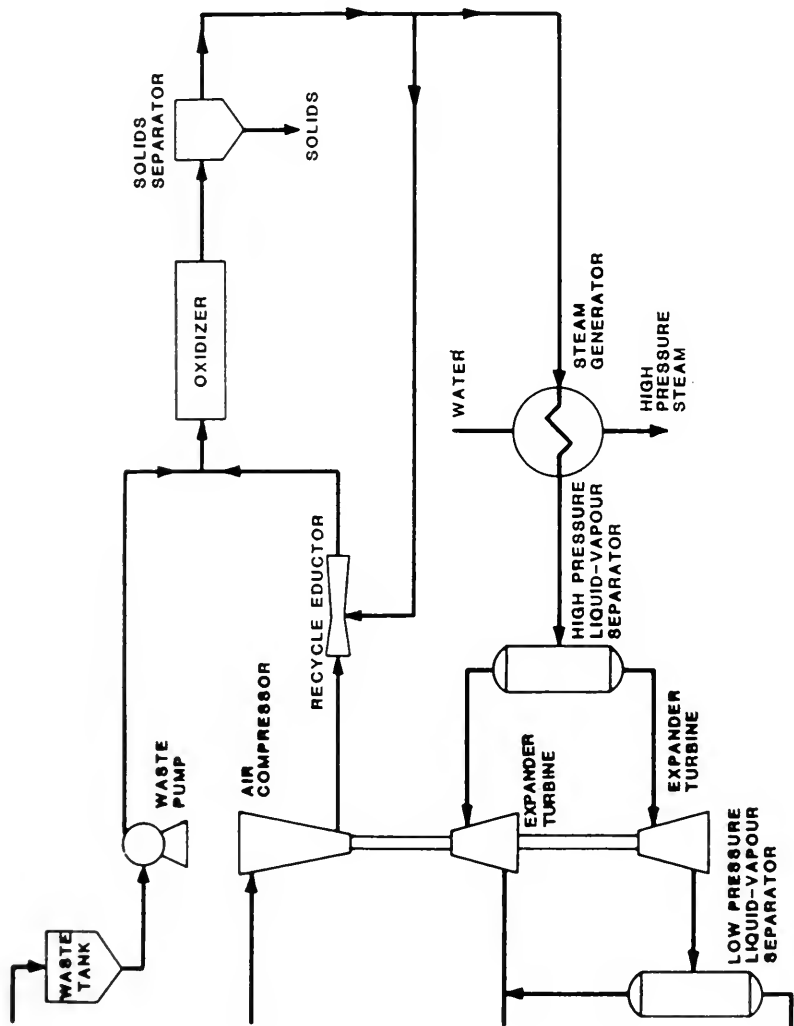
Figure 4-28
SUPERCRITICAL FLUID OXIDATION

which form in the combustion reactions precipitate out of the fluid phase in the oxidizer and are separated.

The fluid discharge of the solid separator consists of superheated, supercritical water, N_2, and CO_2. A portion of this stream is recycled through the eductor to provide supercritical conditions at the oxidizer inlet. The remainder of the effluent is available as a high-temperature, high-pressure fluid for energy recovery. This stream is cooled to a supercritical temperature in a heat exchanger that serves to generate low-pressure and high-pressure steam. Now at a substantial temperature, the mixture has formed two phases and enters a high-pressure, liquid-vapour separator. Almost all of the N_2 and some of the CO_2 leaves with the gas stream. The liquid consists of water with an appreciable amount of dissolved CO_2.

4.4.9   Plasma Systems

Plasma systems use the extremely high temperatures developed within the plasma stream to destroy hazardous organic wastes.

An electric arc is generated and is stabilized by a field coil through which an electric current is passed. As air passes the arc (Figure 4-29), electrical energy is converted to thermal energy by absorption by the nitrogen and oxygen molecules. They are activated into ionized atomic states, losing electrons in the process. Ultraviolet radiation is emitted when the molecules or atoms relax from their highly activated states to lower energy levels.

The resulting gas is in the plasma state and consists of charged and neutral particles with an overall charge near zero and with isolated temperatures over 25 000°C
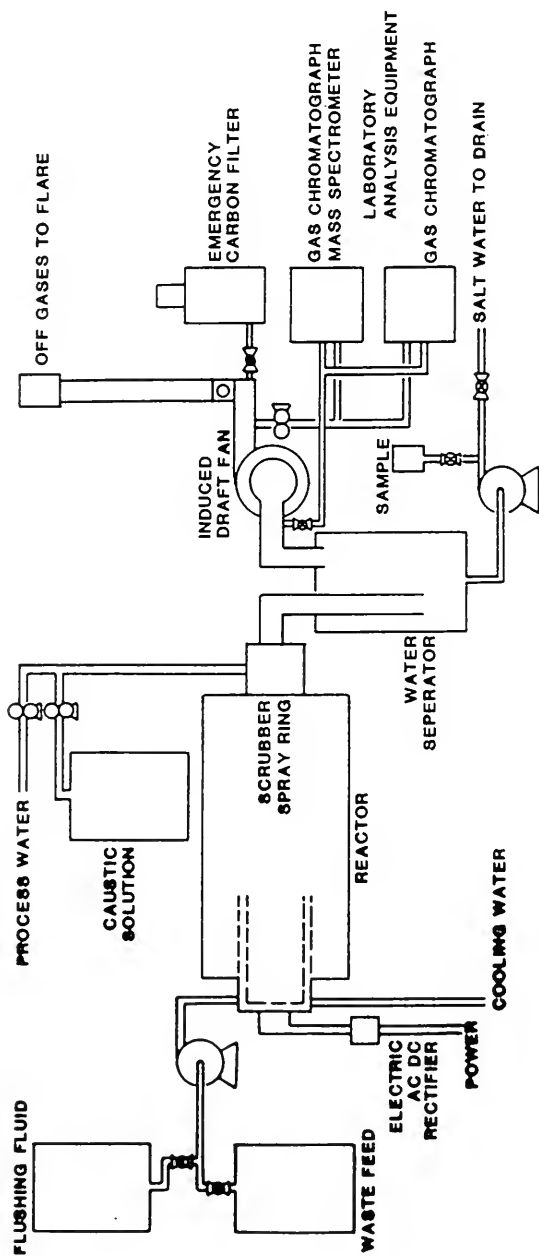
Figure 4-29
PLASMA ARC SYSTEM

(45,000°F). As the activated components of the plasma
decay, their energy is transferred to the waste materials
exposed to the plasma; the wastes are ultimately decayed
and destroyed.

The feed is a liquid stream. Residence time within the
reactor is approximately one second.

Destruction efficiencies in excess of six nines (99.9999%)
have been demonstrated on PCB-contaminated aqueous
streams.

A pilot plant was built to demonstrate process operation.
It was sized to destroy approximately 225 kg/h (496 lb/hr)
of liquids, and fits along with the necessary auxiliary
equipment on a semitrailer. This unit is operational.

The testing of this technology has been the subject of
continuing support from United States regulatory authori-
ties. The fabrication of a mobile unit capable of treat-
ing from 3.5 to 9.5 litres (1 to 2.5 gal) per minute of
waste was completed in the spring of 1984 and is used in a
demonstration of this technology.

4.4.10   Radioactive Waste Treatment

The vast majority of radioactive waste generated is low
level radioactive waste (LLW), which is neither spent fuel
nor high-level waste and contains less than 10 nanocuries
of transuranics per gram of material. Transuranic materi-
al (TRU) refers to uranium or materials, natural or man-
made, with atomic weight equal to or greater than that of
uranium.

Incineration reduces the volume of waste to be disposed
of; it has no effect on radiation itself. Handling, stor-

age, and feeding of material must be carefully controlled. Tight containers and negative ventilation systems exhausting through high efficiency particulate air filters (HEPA) are necessary prior to feeding and incineration.

Incinerator feeding must be designed to preclude the possibility of the escape of hot gases (which may contain LLW) from the incinerator from back-charging into the feeding room when the incinerator charging door is open. This normally requires that the charging system be provided with a series of air locks and multiple feeding chambers to isolate the incinerator gas under all conditions of operation.

Emergency exhaust systems, such as explosion doors used in conventional incineration systems, cannot normally be used when burning LLW. The opening of a door or stack prior to the exhaust gas-cleaning train would discharge LLW to the surrounding air. This requirement may preclude incineration of certain wastes that may cause explosions or the use of supplemental fuel such as natural gas, which is more volatile than other fuels.

The furnace itself in many installations is pyrolytic to minimize gas flow. Off-gas passes first through a permanent type hot gas filter. A HEPA filter will capture residual particulate and after it is spent, the filter is charged to the furnace.

Chapter 5
ENERGY RECOVERY

5.1   INTRODUCTION

Energy recovered from incineration is addressed in this chapter. Heat generated in the incineration process can be used to heat combustion air, reheat the scrubber discharge to eliminate its plume, or generate steam or hot water for various process requirements.

The cost of producing equivalent energy from fossil fuel provides an economic incentive to reclaim the waste heat from incinerators. Additionally, installation of a waste heat recovery system can enable downstream systems, such as scrubbers and other air pollution control units, to be downsized due to the reduced airflow at lower temperatures, thereby decreasing capital and operating costs.

In practice, not all forms of heat recovery systems will be appropriate for any incinerator. Energy recovery by producing hot water or steam for export usually requires relatively constant operation of the incinerator system since the rate of usage is generally continuous. While energy recovery for external use may be practical for larger municipal refuse incineration systems, it is less attractive for mobile or industrial waste incinerators, which normally operate intermittently for several hours per day or week. However, in both continuously and intermittently operated incinerators, the potential for some internal energy recovery from the incinerator flue gas often exists (e.g. heating incinerator combustion air or reheating the scrubber discharge gases).

5.2   ENERGY RECOVERY POTENTIAL

5.2.1   Heat Recovery Media

The potential media for heat recovery systems are air,
water, and steam. Because air has relatively low heat
capacity, its use in heat recovery systems is usually
limited to combustion air heating, scrubber gas reheating,
and seasonal space heating. Additionally, because of the
large volumes of hot air involved and the low heat-
transfer coefficient for air-to-air heat exchangers,
large-diameter ductwork and large plant areas are
required.

Water can be used in heat recovery systems; however, hot
water uses in plants are normally limited to seasonal
space heating and feedwater heating in limited quanti-
ties.

Steam is used for incinerator heat recovery far more
frequently than hot water or hot air. Steam is more
versatile in its application and contains significantly
more energy for the same mass. Steam can be used for pro-
cess requirements for year-round equipment loads; it can
be used to generate electricity; and it can be converted
easily to hot water or used for air heating when these
needs arise.

The following sections present further guidance on the
evaluation of steam-based energy recovery systems.

5.2.2   Available Heat

The available heat in the incinerator flue gas for steam
production is equal to its heat at the boiler inlet less
its heat at the boiler outlet.

For any heat exchanger there is an approach temperature, t_x, which is the difference between the temperatures of the heated medium (t) and the exiting flue gas (t_o).

Thus, $t_x = t_o - t$

The more efficient the heat exchanger, the lower the approach temperature.

In practice, the approach temperature of a waste heat boiler is in the order of 38°C (100°F) for very efficient and 65°C (150°F) for standard, economical construction.

Available heat from a flue gas stream (see Figure 5-1) is calculated as:

$Q = W(h @ t_i - h @ t_o)$

Where:

Q = available heat, kJ/kg
W = flue gas mass, kg/h
h = enthalpy of flue gas, kJ/kg
t_i = temperature of flue gas entering the boiler, °C
t_o = temperature of flue gas exiting the boiler, °C

The flue gas will have a dry and a wet component. Considering the dry gas component to have the properties of air, the above equation becomes:

$Q = W_{dg} (h_{ai} - h_{ao}) + W_m (h_{mi} - h_{mo})$
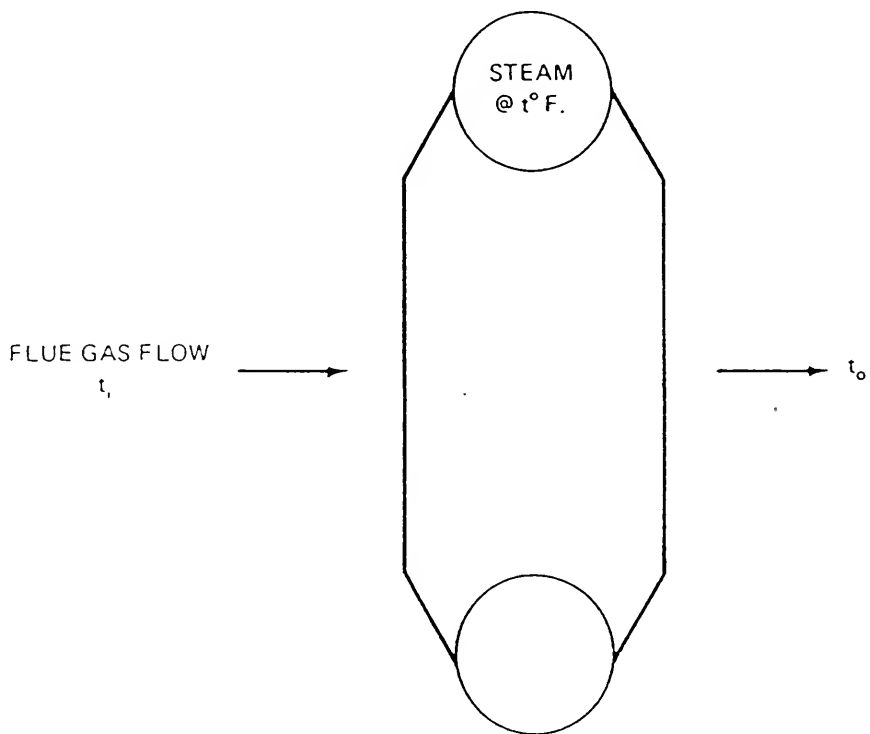
Figure 5-1
WASTE HEAT BOILER

Where:

W_{dg} = flue gas dry component, kg/h
W_m = flue gas wet component, kg/h
h_a = enthalpy of dry gas, kJ/kg
h_m = enthalpy of moisture, kJ/kg

Subscripts i and o correspond, respectively, to flue gas
at the inlet and outlet of the heat exchanger (waste heat
boiler).

5.3   STEAM GENERATION

5.3.1   Steam Generation Systems

Figure 5-2 shows a typical flow diagram for a steam-
producing waste heat boiler. Waste heat from incinerator
flue gas is absorbed in the boiler to produce steam. The
produced steam is used in various plant processes, and the
condensate is returned to the boiler via a deaeration
system that strips dissolved oxygen and carbon dioxide
from the feedwater to control corrosion in the boiler.

Periodic blowdown of the boiler water is required to main-
tain dissolved and suspended solids levels at an accept-
able limit. Blowdown quantity is a function of boiler
water chemistry and the temperature and pressure of the
steam produced. Normally, boiler blowdown ranges from 1
to 5% of the steam generation rate.

Makeup water is required to replace blowdown and any steam
losses in the system. The quality of the makeup water is
determined by both the blowdown rate and particular boiler
characteristics (i.e., pressure, heat transfer rate,
etc.). In general, as boiler pressures increase, feed-
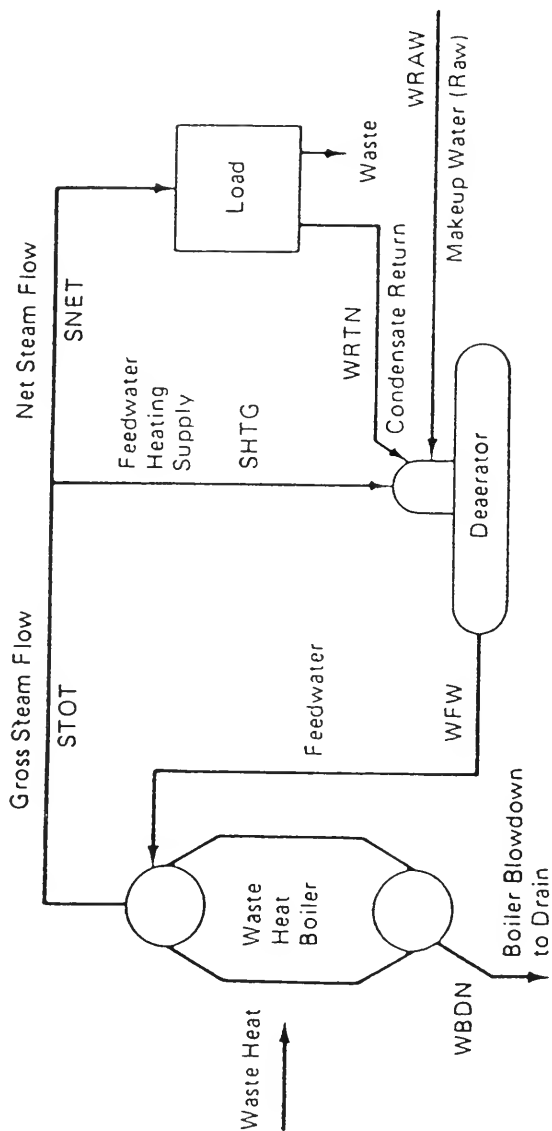
Figure 5-2

WASTE HEAT BOILER STEAM FLOW

water quality requirements become more stringent. Table 5-1 summarizes the ASME water quality guidelines for boilers fired with primary fuels. It is not uncommon for waste heat boilers to suffer from insufficient water-side circulation, areas of unavoidable deposit accumulation, and localized abnormally high heat fluxes. Consequently, it is recommended that a conservative approach be adopted and that demineralized makeup water meeting the specifications for boilers above 6.89 MPa (1000 psig) be provided for waste heat recovery units.

To meet these feedwater quality criteria, makeup water treatment requirements can be extensive; they typically comprise coagulation/precipitation/sedimentation processes, filtration, and ion exchange demineralization. These treatment processes generate waste sludges, dirty backwash water, and regeneration wastes, the disposition of which needs to be considered in the design of the overall waste management plan for an incineration facility.

Similarly, provision must be made for reuse or disposal of boiler blowdown. This waste stream contains the concentrated salts present in the makeup water as well as the chemicals used for internal boiler water treatment or chemical reaction products. Typical chemicals used for internal scaling and corrosion control include phosphates, organic sludge conditioners, chelating agents (EDTA), sodium sulphite, hydrazine, and amines.

5.3.2   Steam Generation Rate

Calculation of steam generation rate includes material (flow) and heat balances around the system. A typical waste heat boiler flow system is shown in Figure 5-2. Using the air and moisture enthalpy tables and the steam tables, calculations can be performed for obtaining steam,

Table 5-1
Suggested Water Quality Limits

Boiler Type: Industrial watertube, high duty, primary fuel fired, drum type
Makeup Water Percentage: Up to 100% of feedwater
Conditions: Includes superheater, turbine drives, or process restriction on steam purity
Saturated Steam Purity Target (9)

Drum Operating Pressure (1)	MPa (psig)	0-2.07 (0-300)	2.08-3.10 (301-450)	3.11-4.14 (451-600)	4.15-5.17 (601-750)	5.18-6.21 (751-900)	6.22-6.89 (901-1000)	6.90-10.34 (1001-1500)	10.35-13.79 (1501-2000)
Feedwater (7)									
Dissolved oxygen (mg/l O_2) measured before oxygen scavenger addition (8)		<0.04	<0.04	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Total iron (mg/l Fe)		≤0.100	≤0.050	≤0.030	≤0.025	≤0.020	≤0.020	≤0.010	≤0.010
Total copper (mg/l Cu)		≤0.050	≤0.025	≤0.020	≤0.020	≤0.015	≤0.015	≤0.010	≤0.010
Total hardness (mg/l $CaCO_3$)		≤0.300	≤0.300	≤0.200	≤0.200	≤0.100	≤0.050	- Not Detectable -	
pH range @ 25°C		7.5-10.0	7.5-10.0	7.5-10.0	7.5-10.0	7.5-10.0	8.5-9.5	9.0-9.6	9.0-9.6
Chemicals for preboiler system protection						Use only volatile alkaline materials			
Nonvolatile TOC (mg/l C) (6)		<1	<1	<0.5	<0.5	<0.5	----- As low as possible, 0.2 -----		
Olly matter (mg/l)		<1	<1	<0.5	<0.5	<0.5	----- As low as possible, 0.2 -----		
Boiler Water									
Silica (mg/l SiO_2)		≤150	≤90	≤40	≤30	≤20	≤8	≤2	≤1
Total alkalinity (mg/l $CaCO_3$)		<350 (3)	<300 (3)	<250 (3)	<200 (3)	<150 (3)	<100 (3)	- Not Specified (4) -	
Free hydroxide alkalinity (mg/l $CaCO_3$)		------------ Not Specified ------------					-Not Detectable (4)-		
Sepcific conductance (µS/cm) (µmho/cm) @ 25°C without neutralization		<3500 (5)	<3000 (5)	<2500 (5)	<2000 (5)	<1500 (5)	<1000 (5)	<150	<100

NOTES FOR TABLE 5-1

1. With local heat fluxes >473.2 kW/m² (>150,000 Btu/hr/ft²), use values for the next higher pressure range.

2. Minimum level of OH⁻ alkalinity in boilers below 6.21 MPa (900 psig) must be individually specified with regard to silica solubility and other components of internal treatment.

3. Maximum total alkalinity consistent with acceptable steam purity. If necessary, should override conductance as blowdown control parameter. If makeup is demineralized water at 4.14 MPa (600 psig) to 6.89 MPa (1000 psig), boiler water alkalinity and conductance should be that in table for 6.90 to 10.34 MPa (10001 to 1500 psig) range.

4. Not detectable in these cases refers to free sodium or potassium hydroxide alkalinity. Some small variable amount of total alkalinity will be present and measurable with the assumed congruent or coordinated phosphate-pH control or volatile treatment employed at these high pressure ranges.

5. Maximum values often not achievable without exceeding suggested maximum total alkalinity values, especially in boilers below 6.21 MPa (900 psig) with >20% makeup of water whose total alkalinity is >20% of TDS naturally or after pretreatment by lime-soda, or sodium cycle ion exchange softening. Actual permissible conductance values to achieve any desired steam purity must be established for each case by careful steam purity measurements. Relationship between conductance and steam purity is affected by too many variables to allow its reduction to a simple list of tabulated values.

6. Nonvolatile TOC is that organic carbon not intentionally added as part of the water treatment regime.

7. Boilers below 6.21 MPa (900 psig) with large furnaces, large steam release space and internal chelant, polymer and/or antifoam treatment can sometimes tolerate higher levels of feedwater impurities than those in the table and still achieve adequate deposition control and steam purity. Removal of these impurities by external pretreatment is always a more positive solution. Alternatives must be evaluated as to practicality and economics in each individual case.

8. Values in table assume existence of a deaerator.

9. No values given because steam purity achievable depends upon many variables, including boiler water total alkalinity and specific conductance as well as design of boiler, steam drum internals, and operating conditions (Note 5). Since boilers in this category require a relatively high degree of steam purity, other operating parameters must be set as low as necessary to achieve this high purity for protection of the superheaters and turbines and/or to avoid process contamination.

makeup, blowdown, and feedwater flows. In performing heat
balance, losses due to radiation should also be included.
Normally, these losses amount to approximately 1% of the
total boiler heat input.

The heat available for steam generation is the heat lost
by the flue gas less the heat lost by boiler radiation.
This heat is absorbed by and stored in steam, blowdown,
and feedwater. Referring to Figure 5-2:

Waste heat = heat in steam + heat in blowdown - heat
in feedwater

Heat in blowdown = WBDN x h_{bdn}

Heat in feedwater = WFW x h_{fw}

Heat in steam = STOT x h_{stm}

STOT = WFW-WBDN   .

Where:

WBDN = Blowdown rate, kg/h
h_{bdn} = Enthalpy of blowdown, kJ/kg

WFW = Feedwater rate, kg/h
h_{fw} = Enthalpy of feedwater, kJ/kg

STOT = Steam generation rate, kJ/h
h_{stm} = Enthalpy of steam, kJ/kg

Usually the blowdown rate is given as a **percentage** of the
feedwater flow.

To calculate steam required for feedwater heating, makeup, and condensate return flows, a material balance and a heat balance must be performed around the deaerator.

Material (flow) balance:

$$WFW = SHTG + WRTN + WRAW$$

Where:

SHTG = Steam supply rate for feedwater heating, kg/h
WRTN = Condensate return rate, kg/h
WRAW = Makeup water rate, kg/h

Heat balance:

$$WFW \times h_{fw} = SHTG \times h_{stm} + WRTN \times h_{ret} + WRAW \times h_{mu}$$

Where:

h_{ret} = Enthalpy of condensate return, kJ/kg
h_{mu} = Enthalpy of makeup water, kJ/kg

If condensate is not returned to the boiler, the steam required for feedwater heating will increase and:

$$SHTG = WFW-WRAW$$

In this case, 12 to 15% of the generated steam is required to heat the makeup water.

Use of condensate return for makeup water heating increases the quantity of steam available for process use. The flow of steam (SNET) is available for useful work.

To calculate available heat for steam generation, the temperature of flue gas exiting the boiler section and entering the air emission control system can be assumed to be in the range of 180°C to 290°C (about 350°F to 550°F).

5.4 DESIGN CONSIDERATIONS

5.4.1 Materials Selection

Normally, ash, inorganic salt compounds, chlorinated and sulphur compounds, and phospho-organics are present in waste incinerator flue gases and deserve special consideration in the design of waste heat boilers. The combination of acidic gases and low-melting-point inorganic salts represents the most severe condition for an energy recovery system.

At sufficiently high temperatures, molten salts and oxides, when cooled, solidify on the waste heat boiler tubing causing fouling, corrosion, and reduced efficiency in the boiler. Ash from waste incineration generally has a high concentration of alkali metal salts and other compounds, such as $NaCl$, Na_2O, $NaFe(SO4)_2$, and $ZnCl_2$, which have melting points well below 800°C (1472°F). In addition, the possible formation of eutectic mixtures (complex combinations of salts with melting points lower than pure salts) will further depress the melting point of the ash. Melting points of some salts and oxides are shown in Table 5-2.

Combustion of phospho-organics results in the formation of gaseous P_2O_5. Above 599°C (1110°F), P_2O_5 reacts with deposits on waste-heat boiler surfaces and with iron oxide on the boiler wall, resulting in difficult-to-remove

incrustations. This causes corrosion and reduces boiler
life and efficiency.

The molten salts problem can be alleviated by cooling the
incinerator exhaust gas below the salt melting point
before it enters the waste heat boiler; this can be accom-
plished by quenching it with water, adding ambient air, or
combining it with recycled gas from the boiler exhaust.
However, reducing the flue gas temperature will reduce the
waste heat boiler's efficiency and decrease its steam
production capacity.

Table 5-2
Melting Points of Some Salts and Oxides
Present in Incinerators

Component, Mole Fraction	°C	°F	Remarks
P_2O_5	569	1056	
$0.50NaCl$--$0.26Na_2SO_4$ --$0.24Na_2CO_3$	612	1134	Tertiary eutectic
$0.65Na_2SO_4$--$0.35NaCl$	623	1153	Binary eutectic
$0.62Na_2CO_3$--$0.38NaCl$	633	1172	Binary eutectic
$NaCl$	801	1474	
Na_2SO_4	884	1623	
Cu_2O	1236	2257	
Fe_2O_3	1462	2664	Decomposition
Fe_2O_3	1560	2826	Decomposition

Incineration of chlorinated organic compounds produces HCl
and some Cl_2 as combustion products. HCl forms hydro-
chloric acid which is extremely corrosive to metal heat-
transfer surfaces when the flue gas temperature is below
the HCl dew point temperature of about 150°C (300°F). On
the other hand, if the temperature of the metal surface is

above 340°C (650°F), high temperature corrosion of the metal surface will occur. The presence of dry hot Cl_2 will also cause severe corrosion.

Combustion of sulphur-containing waste yields SO_2 and SO_3 in the incinerator flue gases. As with HCl, condensation of sulphuric acid and sulphurous acid from the reaction of SO_2 and SO_3 with water vapour is possible.

Therefore, the corrosive/erosive nature of the ash and the presence of acid gas in the flue gas are critical considerations in the selection of operating temperatures (particularly the waste heat boiler outlet temperature) and in selection of materials of construction for the waste heat boilers. These considerations should be addressed on a case-by-case basis, depending on the particular waste being incinerated.

5.4.2   Design Features

In general, flue gas characteristics will dictate the type and design of the waste heat recovery boiler to be used in a specific incineration heat recovery application.

When only acid gases are present in the flue gas, either a fire tube or water tube boiler can be used. In the case of low-concentration, low-melting-point salts only, a specifically designed water tube boiler may be satisfactory. When both acid gases and salts are present, a radiant/convective boiler is necessary.

5.4.2.1 Fire Tube Boilers

In fire tube boilers, the high-temperature flue gases flow through the inside of a tube bundle section, transferring

of the tube bundle. The steam generated is discharged
into a steam drum through several riser pipes. This type
of boiler can be used for hot gases under high pressure.
Fire tube boilers are generally limited to maximum steam
pressures of 10 MPa (1,500 psig).

In this type of boiler, erosion of the tubes can be mini-
mized by controlling the flue gas velocity below 15 m/s
(40 ft/sec). In fire tube boilers, the inside of the
tubes cannot be cleaned during the operation; the buildup
resulting from the presence of low-melting-point compounds
inside the tubes generally precludes their use in this
application.

5.4.2.2 Water Tube Boilers

In water tube boilers, the high-temperature, flue-gas flow
on the outside of the tubes transfers heat to the pressur-
ized water inside. This type of boiler can be used from
relatively low pressure to supercritical steam applica-
tions. Water tube boilers can be designed in a very wide
range of sizes; moreover, it takes only one-third (or
less) the time required by fire tube units to reach full
steam generating capacity. Since the tubes in water tube
boilers have one or more bends, they have more flexibility
for thermal expansion.

To control erosion of the boiler housing from the flue gas
ash particles, certain flue gas velocity limitations
should be observed. The limiting velocity depends on the
ash particle content of the flue gas; however, a velocity
limit of 12 to 18 m/s (40 to 60 ft/sec) is generally
observed.

Water tube boilers may be used for waste heat recovery
from the incineration of a selected waste profile that

produces particulates with relatively low sticking and fusion characteristics. Such boilers should be equipped with efficient soot-blowing mechanisms to allow cleaning of the heat transfer surface during the boiler operation.

5.4.2.3 Radiant/Convective Boiler

Waste heat recovery from "dirty" flue gas containing both acid gases and sticky, low-melting-point particulate is accomplished in radiant/convective-type boilers. The heat transfer surfaces are the boiler walls and internal baffles, which consist of vertical tubes welded together along their lengths to form a continuous heat transfer membrane. Water is force-circulated upward through the tubes and the generated steam is separated in a steam drum. The baffles (tube membranes) are placed perpendicular to the flow of the flue gas as it exits the incinerator, and they are arranged to provide several flue gas passes.

About one-half of the recoverable energy is removed from the flue gases in the radiant cooling chamber. The flue gas then enters the convective section of the boiler across the baffles where further cooling of the flue gas and ash particles takes place. To reduce erosive effects of ash particles, flue gas velocities in the convective section are in the range of 10 to 15 m/s (35 to 50 ft/sec).

Generally, in the last convective pass of the boiler, additional water tubes can be installed to increase the heat transfer efficiency. In a clean boiler, most of the heat transfer takes place in the first one-third section of the unit; however, as fouling progresses, steam genera-tion is shifted from the forward section to the downstream heating surfaces of the boiler.

Chapter 6
EMISSIONS CONTROL

6.1   INTRODUCTION

Incineration generates air emissions, ash, or solid resi-
dues and, depending on the specific incineration process
system used, may produce a wastewater. These discharges
will be significantly less in quantity than the initial
waste stream provided that the incinerator has been prop-
erly designed and operated. In this chapter, the treat-
ment of incinerator discharges is discussed.

6.2   AIR EMISSIONS

6.2.1   Contaminants

The more common air pollutants discharged from incinera-
tors include the following:

°   Particulate matter inclduing metals
°   Inorganic gases
°   Organic gases
°   Acid gas
°   Odour
°   Noise

The generation of each of these pollutants is discussed in
the following subsections.

The standards governing atmospheric discharges are set out
under Regulation 308 of the Environmental Protection Act
(See pg. 2-4 and 2-5 for details). Table 6-1 lists the
current standards, tentative standards, guidelines, and
provisional guidelines as of March 15, 1988. The table is

Contaminant	POI .5h Av ug/m³	AAQC 24h Av ug/m³	LE	ST
Acetic Acid	2500	2500	O	S
Acetylene	56000	56000	O	S
Acrolein	28	23.5	H	TS
Acetone	48000	48000	O	S
Acrylamide	45	15	H	S
Acrylonitrile *	2200	750	H	S
Acrylonitrile	300	100	H	TS
n-alkyltoluenesulphonamide	100	120	T	PG
Alpha Naphthol	100	100	H	G
Aluminum Oxide	100	120	T	PG
Ammonia	3600	3600	O	S
Ammonium chloride	100	120	T	PG
Antimony	75	25	H	S
Arsenic *	75	25	H	S
Arsenic	1	.3	H	TS
Arsine	10	5	H	S
Asbestos	5 #	0.04 9	H	G
Barium-total water soluble	30	10	H	G
Benzene	10000	3300	H	S
Benzo(a)pyrene	3.3 16 ss	0.3 16,6 as	H	PG
		1.1 16,ss		
		0.22 16,6,ss		
Benzothiazole	200	70	H	PG
Benzoyl Chloride	350	125	C,H	PG
Beryllium	0.03	0.01	H	S
Biphenyl	60	60 1	O	G
Boron Tribromide	100	35	C	S
Boron Trichloride	100	35	C	S
Boron Trifluoride	5	2	V	S
Boron	100	100	T	S
Bromacil	30	10	H	G
Bromine	70	20	H	S
n-Butanol		15000 1	I	PG
	2278	3100 18	O	PG
		770	O	PG
n-Butyl Acetate*	15000	15000	I	PG
n-Butyl Acetate		15000 1	H	PG
	735	1000 18	O	PG
		248	O	PG
Butyl Acrylate	100	100	T	G
Butyl Stearate	100	14000	T	G
Cadmium	5	2	H	S
Calcium Carbide	20	10	W	PG
Calcium Cyanide @@	100	100	T	PG
Calcium Hydroxide	27	13.5	C	S
Calcium Oxide	20	10	C	S
Captan	75	25	H	PG
Carbon Black	25	10	S	S
Carbon Disulphide	330	330	O	S

Table 1 (Cont'd)

Carbon Monoxide	6000	36200 1	H	S
		15700 2	Z	S
Carbon Tetrachloride*	20000	7000	H	S
Carbon Tetrachloride	1800	600	H	G
Chloramben	100	120	T	PG
Chlordane	15	5	H	G
Chlorinated Dibenzo	450 17	30 17,6	H	PG
Dioxins, CDDs				
Mixtures of Chlorinated Dibenzo				
Dioxins and Chlorinated Dibenzo Furans, CDFs				
x/450 + y/450(50) = 1	x/30 + y/30(50) =1	H	PG	
	(annual average)			
x=concentration (pg/m3) of CDDs in air				
y=concentration (pg/m3) of CDFs in air				
Chlorine	300	150	H,V	S
Chlorine Dioxide	85	30	H	S
Chlorodifluoromethane	1.05M	350000	H	PG
Chloroform	1500	500	H	G
Chromium *	30	10	H	S
Chromium	5	1.5	H	PG
(Di, Tri, and Hexavalent forms)				
Coal Tar Pitch Volatiles	3	1	H	PG
(soluble fraction)		0.2 6		PG
Copper	100	50	H	S
Cresols	230	75	H	S
Cyclo Sol 63	25000	5000	H	PG
Cyclohexane	300000	100000	H	G
Dalapon Sodium Salt	100	50	H	G
Decaborane	50	25	H	S
Decene-1	180000	60000	H	PG
Detergent Enzyme (Subtilisin) *	1	0.3	H	S
Detergent Enzyme	0.20	0.06	H	TS
Diacetone Alcohol	990	1350 18	O	PG
		335	O	PG
Diazinon	9	3	H	G
Diborane	20	10	H	S
Dibutyltin Dilaurate	100	30	H	G
3,3-Dichlorobenzidine	–	–	H	CAR
Dicapryl Phthalate	100	500	T	S
Diisobutyl Ketone		3500	H	PG
	470	649 18	O	PG
		159	O	PG
Difluorodichloromethane (Freon 12)	1.5M	500000	H	PG
Dimethyl Disulphide	40	40 1	O	S
n,n-dimethyl-1,3-diaminopropane	60	20	H	PG
Dimethyl Ether	2100	2100	O	G
Dimethyl Sulphide	30	30 1	O	S
Dioctyl Phthalate	100	500	T	S
Dioxane		3500	H	G
Dioxolane	30	10	H	PG
Dodecyl Benzene Sulphonic Acid	100	100	T	PG
Dodine	30	10	H	PG
Droperidol	3	1	H	PG
Dustfall	8000 @	7.0 3,4	S	S
Ethyl Acetate	19000	19000 1	O	S
Ethyl Acrylate	4.5	4.5 1	O	S
Ethyl Alcohol	19000	19000 1	O	G
Ethyl Benzene	4000	4000 1	O	S
Ethyl Ether	30000	30000	O,H	TS
Ethyl-3-ethoxy propionate	147	200 18	O	PG
		50	O	PG
		6500	H	PG
2-Ethyl Hexanol	600	600 1	O	G

Table 1 (Cont'd)

2-Ethylanthraquinone	30	10	H	PG
Ethylene	160	40	V	TS
Ethylene Dichloride	1200	400	H	PG
Ethylene Glycol Dinitrate	10	3	H	G
Ethylene Glycol Butyl Ether		2400	H	PG
(Butyl Cellosolve)	350	500 18	O	PG
Ethylene Glycol		3250	H	PG
Butyl Ether Acetate	500	700 18	O	PG
(Butyl Cellosolve Acetate)				
Ethylene Glycol		380	H	PG
Ethyl Ether (Cellosolve)	800	1100 18	O	PG
Ethylene Glycol		540	H	PG
Ethyl Ether Acetate	220	300 18	O	PG
(Cellosolve Acetate)				
Ethylene Oxide *	28500	9500	H	S
Ethylene Oxide	15	5	H	PG
Ethylenediaminetetra-acetic Acid	100	120	T	PG
Fentanyl Citrate	0.06	0.02	H	PG
Ferric Oxide	75	25	S	S
Fluoridation t,GS		40 4,15	V	G
Fluoridation t,NM		80 4,15	V	G
Fluorides G,%%,GS	4.3		V	S
		0.86	V	G
		0.34 4	V	G
Fluorides t, %%,GS	8.6		V	S
		1.72	V	G
		0.69 4	V	G
Fluorides t,%% NM	17.2		V	S
		3.44	V	G
		1.38 4	V	G
Fluorides in forage		80 11,12	A	G
Fluorides in forage		60 11,13	A	G
Fluorides in forage GS		35 11,14	A	G
Fluorinert 3M-FC-70	100	100	T	PG
Formaldehyde	65	65 1	O	S
Formic Acid	1500	500	H	S
Furfural	1000	1000 1	O	S
Furfuryl Alcohol	3000	1000	H	S
Glutaraldehyde	42	14	H	PG
		35 1		
Haloperidol	0.3	0.1	H	PG
Hexachlorocyclopentadiene	6	2	H	PG
Hexamethyl Disilazane	5	2	H	PG
Hexamethylene Diisocyanate Monomer	1.5	0.5	H	PG
Hexamethylene Diisocyanate Trimer	3	1	H	PG
Hexane	35000	12000	H	G
Hexylene Glycol	14400	12000	H	TS
Hydrogen Chloride	100	40	C	S
Hydrogen Cyanide	1150	575	H	S
Hydrogen Peroxide	90	30	H	PG
Hydrogen Sulphide	30	30 1	O	S
Isobutanol	1940	2640 18	O	PG
		655	O	PG
		15000 1	H	PG
Isobutyl Acetate	1220	1660 18	O	PG
		412	O	PG
		12700	H	PG

Table 1 (Cont'd)

	1	2	3	4	5
Isopropyl Acetate	1470	2000	18	O	PG
		500		O	PG
		19000		H	PG
Iron (Metallic)	10	4		S	S
Isopropyl Alcohol	24000	24000		O	G
Isopropyl Benzene	100	100	1	O	PG
Lead	10			H	S
		3	4,5	H	G
		2	4,7	H	G
		5	8	H	G
Lead in Dustfall	0.1 3,4	-		H	TS
Lindane (Hexachloro-cyclohexane)	15	5		H	PG
Lithium Hydrides	7.5	2.5		H	S
Lithium (other than hydrides)	60	20		H	S
Manganese Compounds !!	30	10		H	PG
Magnesium Oxide	100	100		T	S
Malathion	100	300		T	G
Maleic Anhydride	100	30		H	G
Manganese*	100	50		T	S
Manganese	7.5	2.5		H	S
Mercaptans (as methyl mercaptan)	20	20	1	O	S
Mercapto benzo thiazo disulphide	100	100		T	G
Mercury (alkyl)	1.5	0.5		H	S
Mercury	5	2		H	S
Metaldehyde	100	9000	1		PG
		120		T	PG
Methacrylic Acid	2000	2000		O	G
Methane diphenyl di-isocyanate (methylene bisphenyl isocyanate)	3	1		H	TS
Methoxychlor	100	100		T	G
5-methyl-2-hexanone	460	630	18	O	PG
		160		O	PG
		4600		H	PG
Methylal	18000	6200		H	PG
Methyl Acrylate	4	4	1	O	S
Methyl Alcohol	84000	28000		H	S
Methyl Bromide *	12000	4000		H	S
Methyl Bromide	4000	1350		H	G
Methyl Chloride	20000	7000		H	G
Methylcyclopentadienyl					
Manganese Tricarbonyl (MMT)	30	10		H	S
Methyl Ethyl Ketone (2-Butanone)	31000	31000	1	O	S
Methyl Ethyl Ketone	250	80		H	G
Peroxide		200	1		G
Methyl Isobutyl Ketone	1200	1200		O	G
Methyl Methacrylate	860	860		O	S
Methyl-N-Amyl Ketone **					G
Methyl Salicylate	300	100		H	G
4,4 Methylene-Bis-2-Chloroaniline	30	10		H	G
Methylene Chloride	100000	100000	1	O	S
Methylene Dianiline	30	10		H	G
Miconazole Nitrate	15	5		H	PG
Milk Powder	20	20		S,O	S
Monomethyl Amine	25	25		O	S
Naphthalene	36	22.5		H	PG
		50	18	O	PG
Nickel	5	2		V	S
Nickel Carbonyl	1.5	.5		H	S
Nitric Acid	100	35		C	S
Nitrilotriacetic Acid	100	100		T	S

Table 1 (Cont'd)

Nitroglycerin	10	3	H	G
Nitrogen Oxides (as NO$_2$)	500	200	H	S
Nitrous Oxide	27000	9000	H	PG
N-Nitrosodiethylamine	-	-	H	CAR
N-Nitrosodimethylamine	-	-	H	CAR
Octane	45400	61800 18	O	PG
		15300	O	PG
		145000	H	PG
Octene-1	150000	50000	H	PG
Oxalic Acid	75	25	H	PG
Ozone	200	165 1	H,V	S
Palladium (H$_2$O sol.) ##	30	10	H	PG
Penicillin	0.3	0.1	H	G
Pentaborane	3	1	H	S
Pentachlorophenol *	90	30	H,V	S
Pentachlorophenol	60	20	H	G
Perchloroethylene	10000	4000	H	G
Phenol	100	100	O	S
Phosgene	130	45	H	S
Phosphine	30	10	H	PG
Phosphoric Acid (as P$_2$O$_5$)	100	100	H,T	S
Phosphorus Pentachloride	30	10	H	G
Phosphorus Oxychloride	40	12	H	PG
Phthalic Anhydride	100	100	T	S
Pimozide	3	1	H	PG
Platinum in water soluble compounds %	0.6	0.2	H	G
Polybutene-1-Sulphone	100	100	T	PG
Polychlorinated	450 16	150 16	H	G
Biphenyls (risk: .84/m)		35 16,6,10		G
Polychloroprene	100	500	T	G
Potassium Cyanide @@	100	100	T	PG
Potassium Hydroxide	28	14	C	PG
Potassium Nitrate	100	100	T	G
Propionaldehyde	7	10 18	O	PG
		2.5		
Propionic Acid	100	100 1	O	G
Propionic Anhydride (exressed as propionic acid)	100	100 1	O	G
n-Propyl Alcohol	48000	16000	H	G
Propylene Dichloride	2400	2400	O	S
Propylene Glycol Mono-methyl Ether Acetate	5000	5000	O	PG
Propylene Glycol Methyl Ether	89000	121000 18	O	PG
		30000	O	PG
Propylene Oxide*	78000	26000	H	S
Propylene Oxide	13500	4500	H	PG
Pyridine		150	H	PG
	60	80 18	O	PG
Selenium	20	10	H	G
Silane	450	150	H	PG
Silica-respirable (d<10 um)	15	5	H	G
Silver	3	1	H	S
Sodium Bisulphite	100	120	T	PG
Sodium Chlorite	60	20	H	PG
Sodium Cyanide @@	100	100	T	PG
Sodium Hydroxide	20	10	C	PG

Table 1 (Cont'd)

Substance					
7 Solvesso 100		1250		H	PG
	1250	1700	18	O	PG
		422		O	PG
Solvesso 150		2750		H	PG
	1250	1700	18	O	PG
		422		O	PG
Stannous Chloride (as Tin)	30	10		H	PG
Strontium	100	120		T	TS
Strontium Oxide	100	120		T	TS
Strontium Hydroxide	100	120		T	TS
Strontium Carbonate	100	120		T	TS
Styrene	400	400		O	S
Sulphation	0.7	19		X	G
Sulphur Dioxide	830	275		H,V	S
		690	1		S
		55	6		S
Sulphuric Acid	100	35		C	S
Suspended Particulate	100	120		H	S
Matter (d<44 um)		60	6,7		S
Talc (fibrous)	5	2		H	G
Tellurium (except hydrogen telluride)	30	10		H	S
Tetrabutylurea	30	10		H	PG
Tetrahydrofuran	93000	93000		O	S
Tetramethyl thiuram disulphide	30	10		H	G
Thiourea	60	20		H	PG
Tin	30	10		H	S
Titanium	100	100		T	S
Tolmetin Sodium	15	5		H	PG
Toluene	2000	2000		O	S
Toluene Di-isocyanate	1	0.5		H	S
Total Reduced Sulphur (TRS) as equivalent H2S (from Kraft Pulp Mills)	40	40	1	O	PG
1,2,4-Trichlorobenzene	100	400		T	G
1,1,1-Trichloroethane (methyl chloroform)	350000	115000		H	S
Trichloroethylene	85000	28000		H	S
Trifluorotrichloro Ethane	2.4M	800000		H	S
Trimethyl Amine	0.5	0.5	1	O	G
1,2,4-Trimethylbenzene	100	1000		T	G
Tripropyltin Methacrylate	3	1			G
Vanadium	5	2		H	S
Vinyl Chloride	560	280		H	G
Vinylidene Chloride * (1,1-Dichloro Ethene)	26000	8600		H	S
Vinylidene Chloride	70	35		H	PG
Warfarin	30	10		H	G
Whey Powder	100			T	PG
Xylenes	2300	2300		O	S
Zinc	100	100		T	S

DEFINITIONS FOR ABBREVIATIONS IN LIST OF STANDARDS, TENTATIVE STANDARDS, GUIDELINES, AND PROVISIONAL GUIDELINES

A   – Effects on Animals
C   – Corrosion
CAR – Carcinogen with no assigned standard or guideline value.
       Emissions to the environment must be prevented or limited to the
       greatest extent possible.
G   – Gaseous
H   – Health
I   – Irritant property
M   – Million
O   – Odour
P   – Particulate
S   – Soiling
as   – All Sources
ss   – Single Source
t   – Total
T   – TSP (total suspended particulate) standard
V   – Vegetation
W   – Corrosivity of reaction product with water
X   – SO_2 activity
Z   – High background levels from automobiles

GS   – Growing season
       May 1   – September 30 – NE & NW regions
       April 1   – September 30 – other regions
NM   – October 1 – March 31

!!   – Including Potassium Permanganate as Manganese
@   – ug/m2
@@   – As total salt
#   – Total Asbestos
– Water soluble forms including Palladium Chloride as Palladium
%   – Including Hexachloroplatinic Acid as Platinum
%%   – As HF
*   – changed, lowest value in effect
**   – under review, for details see contact

1   – 1 hour
2   – 8 hour
3   – g/m^2
4   – 30 day
5   – arithmetic mean
6   – 1 year
7   – geometric mean
8   – single sample
9   – fibres per cc, of length > 5um
10   – average
1   – ppm
12   – dry weight, any single month
3   – dry weight, average of 2 consecutive months

```
14  - dry weight, average of monthly results for growing season
15  - ug total fluorides/100 cm² limed paper
16  - ng/m³
17  - pg/m³
18  - 10 minute
19  - mg SO₃/100 cm²/day
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POI  - Point of Impingement           -  ug/m³
AAQC - Ambient Air Quality Criterion   -  ug/m³
LE   - Limiting Effect
ST   - Type of Standard :
S    - Standard, appears in O.R.308
TS   - Tentative Design Standard, set by EASSC
G    - Guideline, set by EASSC
PG   - Provisional Guideline, set by EASSC
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EASSC-Environmental Air Standards Setting Committee

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a    - average
cm   - centimetre
cm³  - cubic centimetre
cm²  - square centimetre
d    - days
g    - gram
h    - hour
m³   - cubic metre
mg   - milligram - 10-3  g
m²   - square metre
ng   - nanogram  - 10-9  g
pg   - picogram  - 10-12 g
ppm  - parts per million
ug   - microgram - 10-6  g
um   - micrometre
y    - year
```

Computation of values for various averaging times for standards and guidelines based on the limiting effect of odour, for continuous sources following classical plume behaviour.

$$C = OT(0.t)^{-.28047}$$

where: OT = odour threshold, 50% detection level
        t = time in minutes

contact: For additional information contact Emission Technology and
          Regulation Development Section, Air Resources Branch,
          Ontario Ministry of the Environment
          416-965-5776

continually being updated and the reader should check with
the Ministry to determine the current status of this
information.

Policy 01-03 and its interim guideline (see Appendix B)
relate to the use of state-of-the-art air pollution con-
trol, and include particulate and hydrogen chloride
emission limits from refuse incinerators.

6.2.1.1 Particulate Matter

The most visible discharge from a burning process is
smoke. Smoke and other particulate matter, or aerosols,
are defined by size, as shown on Figure 6-1. One micron,
μ, is one-millionth of a metre and is commonly used to
describe particulate size. Smoke is a suspension of solid
or liquid particulate matter in a gaseous discharge. The
particles range from fractions of a micron to over 50
microns in diameter. The visibility of smoke is related
to the quantity of particles present, rather than to the
weight of the particulate matter. The weight of particu-
late emissions is, therefore, not necessarily indicative
of the density of the emission. Neither is the colour of
a discharge related to opacity or smoke density. Smoke
can be black or can appear nonblack; in the latter case,
it is termed "white smoke." These two types of smoke are
discussed below:

°   White smoke: The formation of white or other opaque,
    nonblack smoke is usually due to insufficient furnace
    temperatures when burning carbonaceous materials.
    Hydrocarbons will be heated to a level where evapora-
    tion and/or cracking will occur within the furnace
    when white smoke is produced. The temperatures will
    not be high enough to produce complete combustion of
    these hydrocarbons. With a stack temperature in the
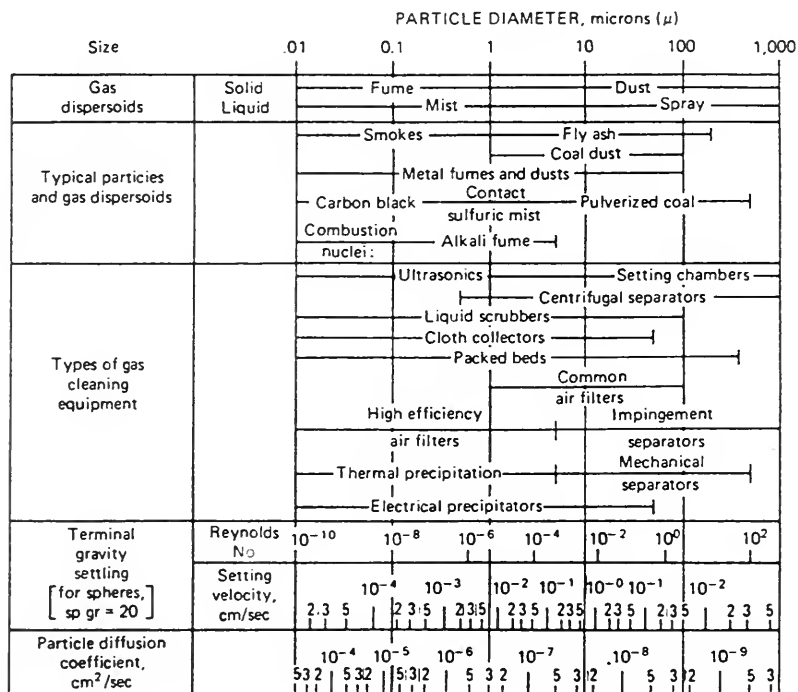
Figure 6-1
PARTICULATE MATTER BY SIZE

SOURCE : FROM CHEMICAL ENGINEER'S HANDBOOK, R. PERRY,
C. CHILTON, FIFTH EDITION, McGRAW HILL 1973, PAGE 20-79

range of 150°C to 260°C (300°F to 500°F), many of these hydrocarbons will condense to liquid aerosols; with solid particulate present, these will appear as nonblack smoke.

A method for controlling white smoke is to increase the furnace/stack temperatures and increase turbulence to help ensure uniformity of this hig temperature within the off-gas flow.

Excessive airflow may result in excessive cooling. An evaluation of reducing white smoke discharges should include investigating the air quantity introduced into the furnace. Inorganics in the exit gas may also produce a nonblack smoke discharge. For instance, sulphur and sulphur compounds will appear yellow in a discharge; calcium and silicon oxides in the discharge will appear light to dark brown.

° Black smoke: When burned in an oxygen-deficient atmosphere, hydrocarbons will not completely destruct, and carbon particles will be found in the off-gas. Causes of local oxygen deficiency include poor atomization, inadequate turbulence (or mixing), and poor air distribution within a furnace chamber. Each of these factors will generate carbon particles that produce dark, black smoke in the off-gas.

A common method of reducing or eliminating black smoke has been steam injection into the furnace. The carbon present is converted to methane and carbon monoxide as follows:

$3C$ (smoke) $+ 2H_2O \rightarrow CH_4 + 2CO$
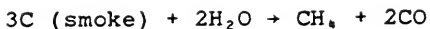
Hydrocarbons react similarly, and the methane and carbon monoxide produced burn clean in the heat of the furnace, eliminating the black carbonaceous smoke that would have been produced without steam injection:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ (smokeless)

$2CO + O_2 \rightarrow 2CO_2$ (smokeless)

Steam injection normally requires from 9 to 40 kg (20 to 80 pounds) of steam per pound of flue gas.

It should be noted that there is some controversy regarding the effect of steam injection into carbon-aceous discharges. Some argue that the steam primarily produces good mixing.

Metallic particulate discharges into the atmosphere gener-ally account for less than 1% of the total particulate discharge. However, many of these metals generate com-pounds that can have severe, toxic effects.

6.2.1.2 Inorganic Gases

Inorganic gases produced from the burning process normally include water vapour, carbon dioxide, carbon monoxide, oxides of nitrogen, and, when sulphur is present, oxides of sulphur.

Nitrogen is an extremely active substance that forms nitrogen oxide (NO) and nitrogen dioxide (NO_2) from the combustion process.

Sulphur is released into the atmosphere from burning processes in the form of sulphur dioxide, SO_2, and sulphur trioxide, SO_3.

6.2.1.3   Organic Gases

Of the many organic discharges from incinerators, the more significant ones are:

°   Oxygenated hydrocarbons, which include aldehydes, ketones, alcohols, and acids. In sufficient quantity they will produce eye irritation, reduce visibility in the atmosphere, and react with other components of the atmosphere to form additional pollutants. Many of these compounds are also odourous.

°   Halogenated hydrocarbons, such as carbon tetrachloride, perchloroethylene, etc. These may contribute to atmospheric clarity problems and may also generate odour.

°   Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzo-furans (PCDF). These compounds may be formed when materials containing chlorine are incinerated. These compounds are of considerable concern due to their toxicity in trace quantities to laboratory animals.

°   Olefins, which are a group of unsaturated hydrocarbon compounds that readily react with many other chemical compounds. Olefins take part in photochemical reactions in the presence of nitrogen oxides and several other pollutants.

°   Aromatics, including benzene, toluene, xylene, and polycyclic aromatic hydrocarbons (PAH). One of the

most toxic of these occurring in industrial processes
is benzo(a)pyrene (also written as 3,4,benzopyrene).
This compound is relatively simple to detect. A pri-
mary source of these compounds is the incomplete
combustion of organic materials.

The most apparent effect of organic gas discharges is
their effect on the atmosphere. They react with other
elements of the atmosphere to form photochemical smog,
which is as much a danger to health as it is to the
aesthetic quality of an area.

6.2.1.4 Acid Gas

Industrial waste will often have either a halogen or sul-
phide component. Municipal wastes have relatively high
proportions of plastics, and many of these materials have
a significant amount of chlorides. Chlorides and/or sul-
phides in an incinerator charge will produce hydrogen
chloride and/or chlorine, and sulphur dioxide/trioxide gas
in the exhaust stream. Acid gas neutralization systems
should be provided when significant quantities of hydrogen
chloride are present in an exhaust. Control of these
emissions is often necessary for the protection of down-
stream equipment.

6.2.1.5 Odour

Odours associated with incineration are normally organic
and result from the incomplete combustion of organic mat-
ter in the waste feed. The most effective means of deal-
ing with the problem of odour generation is alteration of
the burning process to increase burning efficiency, there-
by decreasing the occurrence of odour-causing compounds in
the exhaust stream.

Since waste streams vary in chemistry or quality, the efficiency of the waste-burning process can also change, and combustion parameters must be adjusted to reduce the possibility of odour generation.

Secondary odours may originate from equipment and systems within the incinerator facility such as storage tanks, waste storage pits, etc. Where practical, ventilation systems should be designed to contain such odours and to bring the odourous air to the incinerator for destruction. Other mechanisms of odour control may be required, such as fume incineration, use of a packed tower (absorber), catalytic oxidation system, adsorbtion (using carbon on silicon beds), dilution, or masking.

6.2.1.6 Noise

Noises generated by an incineration facility are generally those resulting from the movement of air or gas. Fans and blowers will create the greatest noise levels; of secondary concern is the noise generated by passage of air or gas through ducts, flues, and nozzles.

In addition to local noise, sound can be broadcast to areas surrounding the plant outside the facility limits. Table 6-2 lists typical sound levels encountered in the course of a day. Broadcast noise can be within the levels listed; however, a fan in constant operation producing a constant drone may become an annoyance and result in a complaint to plant operators.

Local noise can usually be controlled by initial equipment selection, use of sound-absorbing equipment, and provision of sound-deadening or sound-absorbing enclosures around noisy equipment. Exterior noise, however, can be broad-

Table 6-2
Average Single Number Sound Levels, dBA

Interior Noise

Bedroom at night	30- 40
Small office or store	47- 59
Large store	51- 63
Large office	57- 68
Electric typewriter at 3 m	62- 67
Automobile	64- 78
Garbage disposal	78- 83
Airplane cabine	88- 98

Noises 1 m From Source

Whispering	30- 35
Quiet ventilating outlet	41- 47
Quiet talking	59- 66
Noisy ventilating outlet	60- 75

Noise 1 m From Source

Lathe	73- 83
Shouting	74- 80
Power saw	93-101
Power mower	94-102
Farm tractor	94-103

Outside Noises

Leaves rustling	10- 15
Bird call	40- 45
Quiet residential street	40- 52
Edge of highway with dense traffic	70- 85
Propeller plane at 30 m	75- 84
Pneumatic drill at 15 m	80- 85
Noisy street	84- 94
Jet plane at 300 m	100-105
Jet take-off at 60 m	120-125
37 kW siren at 30 m	130-135

SOURCE: Noise and the Environment, USEPA Journal, October
         1979.

cast hundreds of metres, perhaps kilometres. The usual
cause of broadcast noise is the pulsation of the ID fan.

Sound control equipment sizing is proportional to the
wavelengths of the sound generated. The lower the fre-
quency, the longer the wavelength and the larger the sound
control equipment. In controlling ID fan broadcast noise,
therefore, it is first necessary to try to increase the
beat frequency. If possible, the fan speed should be
increased, or if this is impractical, the number of blades
should be increased. The ID fan should be close-coupled
to the stack. Ductwork with appropriate expansion joints
will tend to absorb some of the potential broadcast
noise.

Two types of insertion sound control devices are used to
reduce broadcast noise. The first is an exhaust silencer,
which is placed within the stack or between the ID fan and
the stack. These are resonating devices that tend to bal-
ance the generated beat by producing (by static geometry)
a frequency that is 180 degrees out of phase from the fan
beat. The net result, ideally, is cancellation of the
beat frequency plus harmonics. The second type is a baf-
fle, usually perforated, that absorbs sound energy with
its acoustical fill: fiber glass, mineral wool, or other
absorbent.

Standards applicable to noise/sound control are discussed
in Section 3.2.4.

6.2.2   Air Emissions Control Devices

Many types of equipment are available for use in control-
ling air emissions from incinerators. These include the
following:

°   Inertial systems
°   Fabric filters
°   Electrostatic precipitators
°   Wet scrubbing systems
°   Dry scrubbing systems

The following is a discussion of the basic principles and applications for each of these common air emission control devices.

6.2.2.1 Inertial Systems

Inertial systems provide a relatively inexpensive means to remove medium-sized and larger particulate matter from the gas stream (over 15-micron mean particle size). They are normally used in conjunction with other air emission control devices because, alone, they cannot provide sufficient emissions reduction.

Inertial separators operate by the principles of gravitational and/or centrifugal force to remove particulates from the gas stream. Dry inertial systems are effective only with particulate matter and, when properly designed, can provide some noise attenuation. Wet systems can be used to reduce gas or control odours.

Inertial air emissions control systems include the following:

°   Settling chambers
°   Baffles
°   Dry cyclonic separators

°   Wet cyclonic separators
°   Dry scrubbing

A settling chamber is a stilling chamber where the veloci-
ty of a gas is decreased or remains unchanged from the
previous process and particles fall from the gas stream by
gravity. Settling chambers are used for very large parti-
cles, typically 500 microns or greater in size.

Baffles are walls or plates inserted in the gaseous flow
stream to act as walls for the flowing particulate matter.
The gas stream flows around the baffles; however, the par-
ticles, generally above 15 microns, will be stopped by the
obstruction and drop to the chamber floor for collection
and subsequent removal.

A cyclone is a versatile, low-cost centrifugal separator
that can be designed to handle a wide range of chemical
and physical conditions of operation. Cyclones are effic-
ient for the removal of larger particles, greater than 15
microns, but are less efficient for removal of smaller
particles. The use of a cyclone reduces the particulate
loading on downstream equipment. A cyclone separator is
often placed upstream of other control devices such as an
electrostatic precipitator or a baghouse. Cyclones are
designed to operate either in a wet or dry mode.

The dry cyclonic separator separates particulate matter
from the gas by transforming the velocity of an inlet
stream into a double vortex confined within the cyclone.
Particulates within the gas stream move toward the outside
wall. The particles drop from the wall inside the cyclone
to an external receiver for eventual disposal. One poten-
tial problem with the dry cyclonic separator is that some
particulate matter may cling to the walls rather than drop
down for collection.

Two types of wet cyclonic separators can be used with incineration systems. One is a modification of the dry cyclone in which water is injected at the top of the cyclone to wash the walls free of collected particulate matter. A second type of wet cyclonic separator uses a damper at the entrance to the cyclone. The damper restricts the flow entering the cyclone chamber and imparts a high-velocity spin to the gas stream. Liquid spray is introduced into the rotating gas from an axially located manifold in the lower part of the unit. The atomized fine spray droplets are swept across the walls of the cylinder by centrifugal force and absorb and collect the particulate matter. The spent water generated from either device is collected, treated, and reused or discharged from the system. Examples of typical dry and wet cyclonic separators are presented in Figures 6-2 and 6-3, respectively.

6.2.2.2   Fabric Filters

Fabric filters are commonly used in all types of industrial particulate control applications. The types of filters of interest in incineration applications are the baghouse and the high-efficiency particulate air (HEPA) filter.

Baghouses are the most common air pollution control filtration systems. A typical system is shown in Figure 6-4. The fabric filter material is formed into cylindrical bags, and a series of these bags is suspended within a structure called a baghouse. The dirty gas passes through the permeable fabric, leaving the particulates either on the inside or the outside of the bag, depending on the filtering arrangement. Particles are captured and retained on the fibres of the cloth by means of interception, impingement, diffusion, gravitational settling, and electrostatic attraction.
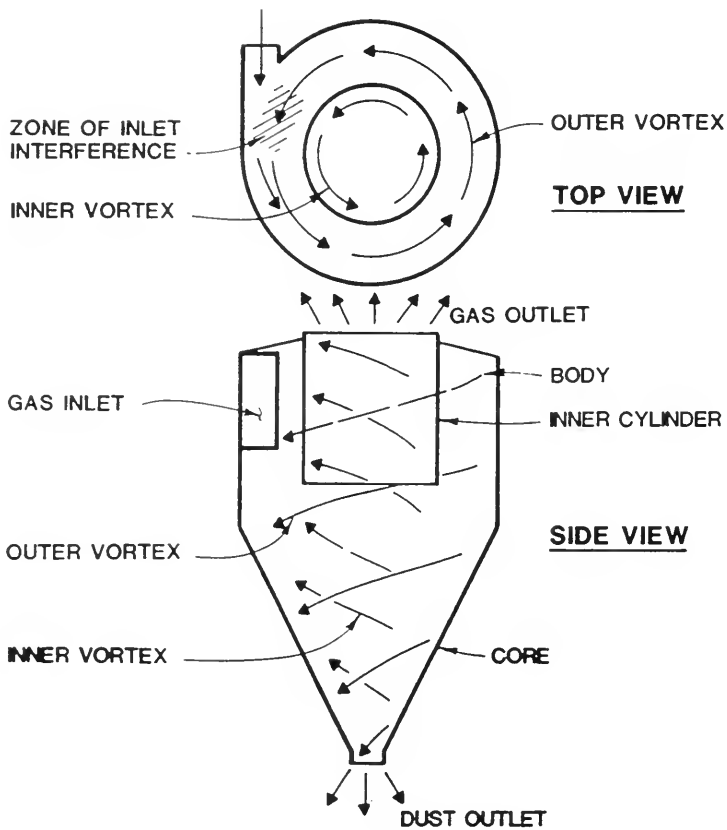
Figure 6-2
DRY CYCLONIC SEPARATOR
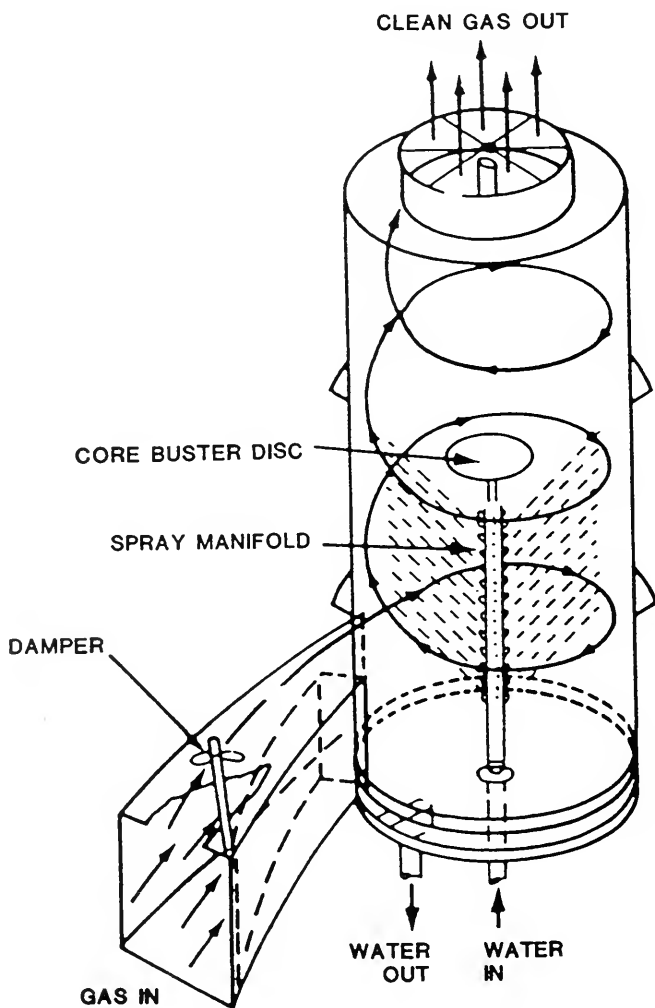
Figure 6-3

WET CYCLONIC SEPARATOR
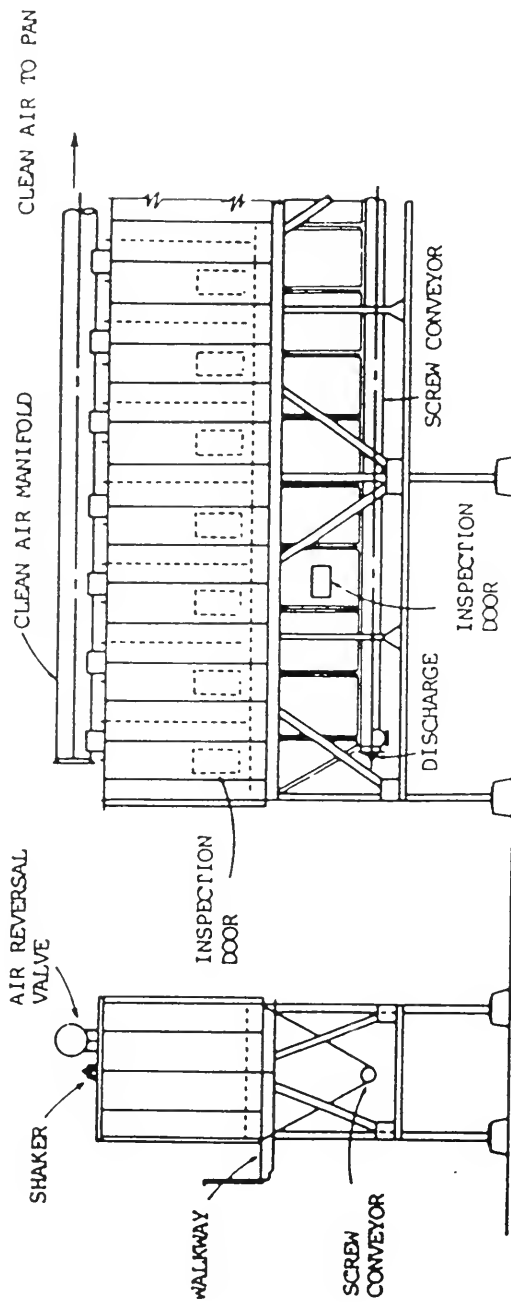
Figure 6-4

TYPICAL BAGHOUSE ASSEMBLY

The filtering media selected for use in a baghouse must be compatible with the temperature and chemical content of the flue gas. In addition, a number of other items must be considered in the selection and design of the baghouse. The baghouse should be designed to provide the degree of filtration required, the longest possible bag life, the ability to properly clean the bags on an automatic and regular basis, and an adequate gas and dust distribution system.

The filter fabric serves as the supporting structure for the dust mat. Periodically, the accumulated dust must be removed for disposal. A major feature of a baghouse is its ability to discharge the accumulated particulate cake; therefore, baghouses are categorized by the type of cleaning method used, as follows:

- ° Reverse pulse
- ° Shaker mechanisms
- ° Reverse flow
- ° Reverse jet
- ° Sonic cleaning

Reverse pulse uses a series of strong, short pulses of air that pass through a venturi tube at the top of the bag to exert the cleansing action. The particulate matter builds up on the outside of the bag. After a period of filter cake buildup, reverse air pulses cause the cake to fall off into a hopper for collection and removal.

In a shaker mechanism, an eccentric rod physically shakes the bags, causing the caked particles to fall into the bottom of a silo for eventual removal. Often fresh air is simultaneously admitted to a damper section to aid in the discharge of the collected dust.

In a reverse flow system, baghouses are cleaned by forcing air through the bags in a direction opposite that of normal flow. The reverse flow cleaning air collapses the bag inward; when the bag is brought back online, it expands and dislodges the cake, which falls into a hopper.

The reverse jet system uses a jet manifold that surrounds each bag and continuously moves up and down, blowing the accumulated cake away.

The sonic cleaning method uses an intense sound source that is tuned to create vibration that causes the dust to fall from the bags for collection and eventual removal. It can be used alone or in combination with shaker and reverse air systems.

High-efficiency particulate air (HEPA) filters are used where removal of small particulate matter is required such as incinerators firing low level nuclear-contamined waste streams. HEPA filters are normally used for particle sizes below 2 microns and have excellent removal efficiencies for particle sizes less than one micron. Incinerator exhaust gas streams that have a significant moisture content must pass through a drying system to avoid clogging the filter. In addition, HEPA filters have poor resistance to high temperatures, and incinerator flue gases must be cooled to below 90°C (200°F) for many applications.

A typical HEPA filter, as shown in Figure 6-5, is mounted in a frame. A series of frames is then mounted in a filter bank to provide the required flow capacity.
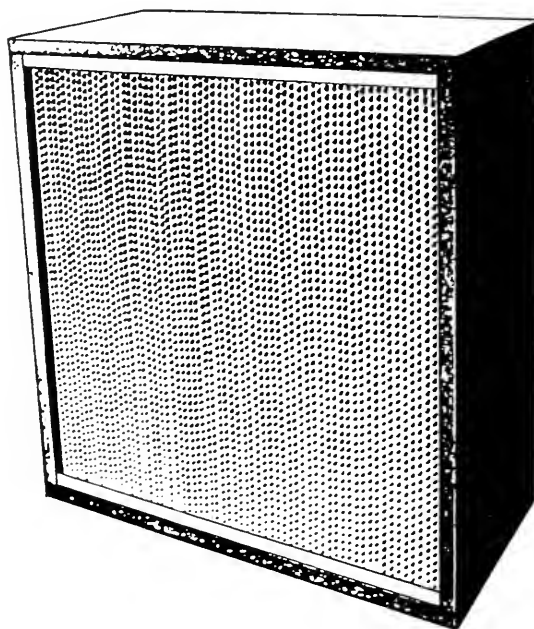
Figure 6-5

HEPA FILTER

(Source : American Air Filter Co., Inc., Louisville, KY.)

6.2.2.3 Electrostatic Precipitators

Electrostatic precipitators (ESPs) are effective devices
for the removal of airborne particulate matter. Electro-
static precipitation is a process by which particles
suspended in a gas are electrically charged and separated
from the gas stream under the action of an electric
field.

Electrostatic precipitation consists of the following
elements:

°   Gas ions are formed by means of high-voltage corona
    discharge.

°   Solid or liquid particles are charged by bombardment
    by the gaseous ions or electrons.

°   An electrostatic field causes the charged particles to
    migrate to a collecting electrode of opposite
    polarity.

°   The charge on the particle is neutralized by the
    collecting electrode.

°   The collected particles are removed from the collect-
    ing electrode for subsequent disposal.

Two basic types of ESPs are used for municipal and indus-
trial incinerator emissions control: the conventional ESP
and the wet ESP.

The typical conventional (dry) ESP, shown in Figure 6-6,
is effective for the collection of fine particles less
than one micron in diameter. The efficiency of an ESP is
highly sensitive to variations in flue gas temperature and
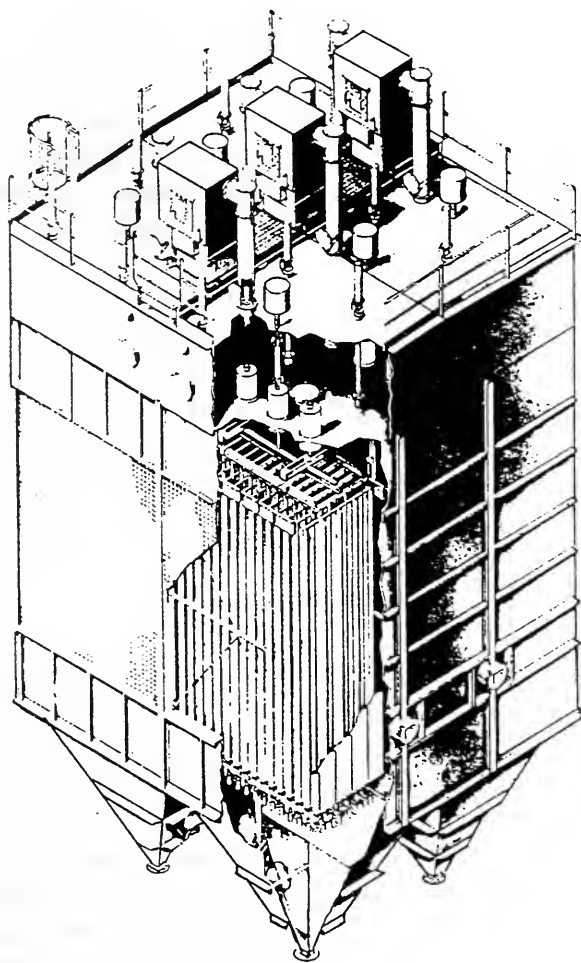
Figure 6-6
TYPICAL ELECTROSTATIC PRECIPITATOR

to humidity, dust concentration, collection area, and resistivity of the particulate matter.

The wet electrostatic precipitator is a variation of the conventional dry ESP design. The two additional features are (1) a preconditioning step in which the entering gas is sprayed with water to reduce its temperature, remove larger particles, and provide some acid gas adsorption; and (2) a wetted collection surface where liquid is used to continuously flush away collected materials.

The wet ESP overcomes some of the limitations of the dry electrostatic precipitator by eliminating the influence of particle resistivity, controlling the buildup of tacky particles, and providing some capacity for removal of gaseous pollutants. A major disadvantage of this system is the generation of a waste liquid stream that must be disposed of.

6.2.2.4 Wet Scrubbing Systems

Wet scrubbers are more universal systems since they can function as particulate and, in some cases, gas and odour control devices. Scrubbers remove particulate matter mainly by inertial impaction and gases by absorption.

Wet scrubbing systems use a scouring action to remove particles from a gas stream. The scrubbing action is primarily a function of particle geometry or physical dimension. Wet scrubbing systems bring particulate matter in contact with liquid droplets that wash the particulates out of the gas stream.

Wet scrubbing systems used for incinerator air emissions include:

°   Spray chambers
°   Spray towers
°   Venturi scrubbers
°   Tray scrubbers
°   Self-induced scrubbers
°   Dry scrubbers

A spray chamber is a simple type of scrubber in which
spray nozzles are placed inside a chamber. The gas stream
velocity decreases as it enters the chamber, the gas is
washed with a liquid, and the wetted particulate matter
within the gas is removed with the drained liquid. Spray
chambers are used extensively as gas coolers and primarily
for removing the heavier particulate matter.

Spray towers remove contaminants by a gas absorption pro-
cess. The scrubbing liquid is atomized by high-pressure
spray nozzles into small droplets, which are then directed
into a chamber through which the gas passes. Spray towers
are used for simultaneous gas absorption and dust
removal.

A typical venturi scrubber is a flue with a constricted
throat, as shown in Figure 6-7. Liquid is injected into
the high-velocity gas stream either at the inlet to the
converging section or at the venturi throat. The turbul-
ent gas atomizes the liquid into fine droplets, which
provide a large surface area for gas/liquid contact that
permits the adsorption of contaminants. As the throat
opens, the gas velocity decreases and water particles
leave the gas stream.

Venturi scrubbers are used to remove gas stream particul-
ates down to approximately 1 micron mean particle size.
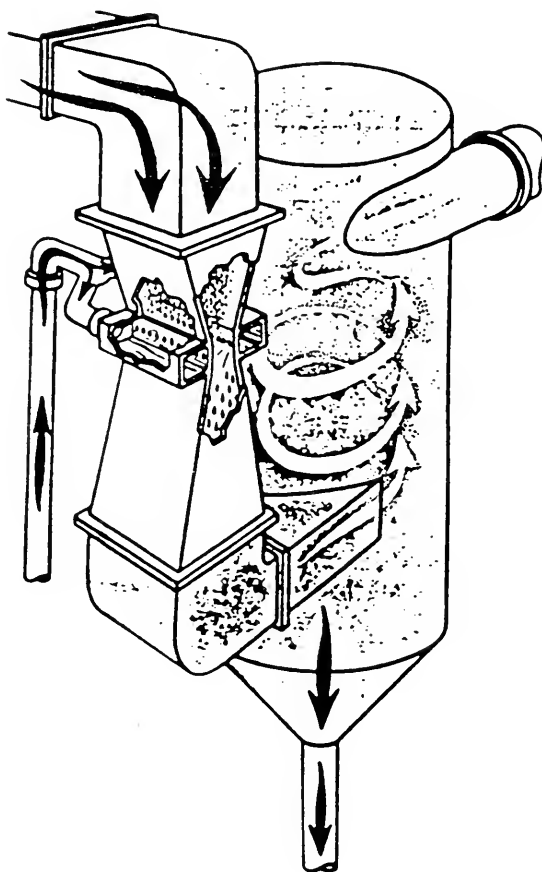
Figure 6-7
VENTURI SCRUBBER

Tray scrubbers are perforated plates with target baffles. The water level is maintained above a stack of two or three trays. The geometrical relationship of the tray thickness, the hole size and spacing, and the impinger details result in a high efficiency device for the removal of particles less than 2 microns in diameter. Normally, a venturi scrubber or an inertial separator is placed immediately in front of a tray scrubber.

A number of wet scrubbers employ a unique geometry that utilizes the gas flow to generate scrubbing action. These self-induced scrubbers are able to obtain relatively good particulate removal efficiency while using relatively low gas differential pressures. In a typical unit, as shown on Figure 6-8, the water level controls the scrubbing action of the gas. The higher the water level, the greater, or longer, the contact between the gas stream and the water particles.

6.2.2.5 Dry Scrubbing Systems

Dry scrubbers have been used in the electric power industry, specifically with coal-burning power plants, for a number of years. Recently, this technology has been adapted to control particulate and acid gas incinerator emissions. (It is included in this chapter because its operation is similar to that of a wet scrubber and water is often added to the gas stream, although not enough water to produce a condensate.) A particulate collection device (fabric filter or ESP) is required downstream of the dry scrubber.

The Framingham Refuse Reduction Facility in Massachusetts was the first incinerator in North America to utilize dry scrubbing. The system consists of two basic components: an Upflow Quench Reactor (Figure 6-9) and a Dry Scrubber
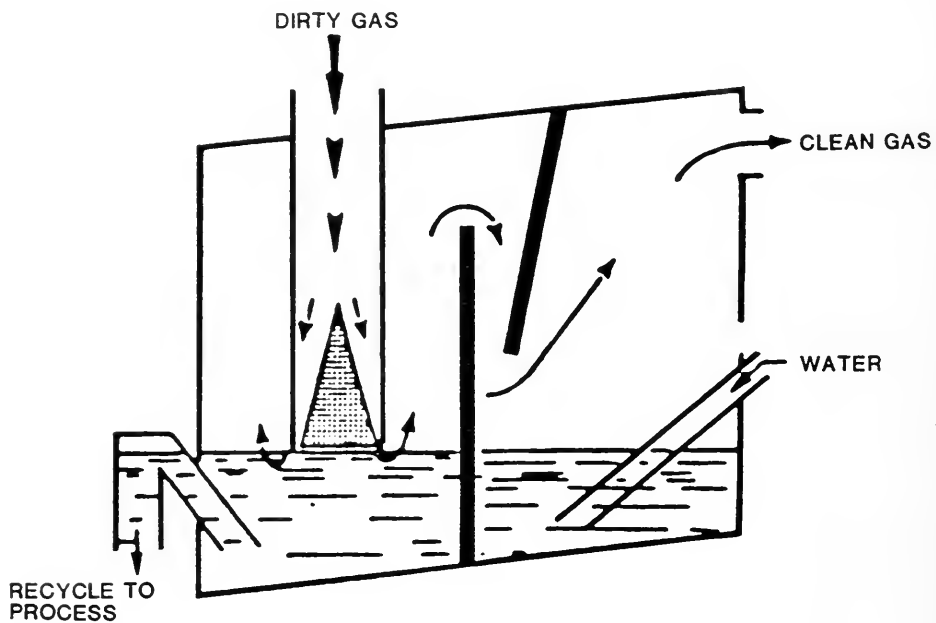
Figure 6-8
SELF-INDUCED SPRAY SCRUBBER
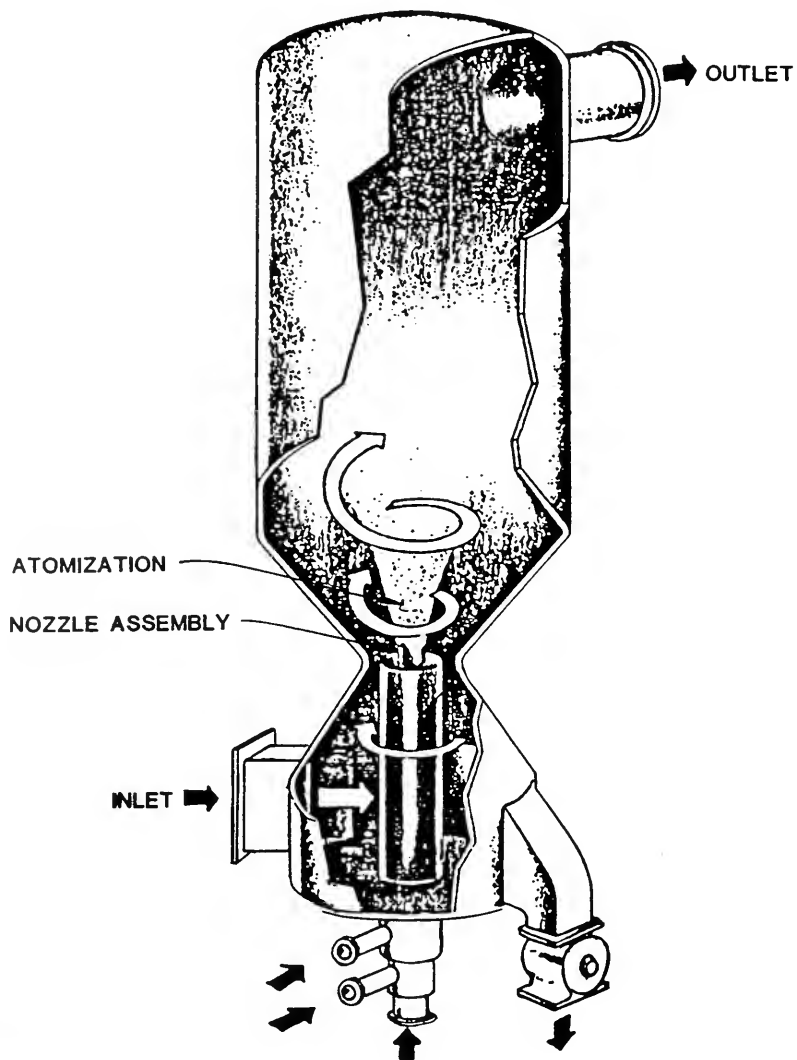
Figure 6-9
UPFLOW QUENCH REACTOR

(Figure 6-10). Systems are available from many manufac-
turers (Flakt, Niro, Teller, etc.) and have been applied
to refuse and industrial incinerator systems in Europe and
in North America.

In a typical system hot incinerator exhaust gas enters the
inlet of the quench reactor, a cyclonic element where
larger particles drop out of the stream by inertial
forces. Rising through the reactor, an alkali solution is
sprayed into the swirling gas stream and fully wets it.
The alkali (a lime slurry or sodium carbonate solution)
neutralizes the acid component of the gas and quenches any
sparklers within the gas flow. The reactor is designed to
promote neutralization of the acidic gaseous components by
formation of an alkali mist within the reactor.

The neutralized gas stream leaves the quench reactor at
its adiabatic temperature, normally from 65°C to 80°C
(150°F to 180°F) and passes through the dry scrubber. A
highly crystalline inert material, from 3- to 20-micron
particle size, is injected into the gas stream through the
venturi. Either talc or waste product fines from various
manufacturing industries can be used. Other systems (dry/
dry systems) inject dry lime into the gas stream and
utilize the lime as a sorbant. The gas moisture content
must be controlled to 17% or greater for these dry/dry
systems to function properly.

Within the venturi, the generated turbulence will tend to
complete the neutralization process. In addition, the
injected powder will adsorb particulate matter within the
gas stream and will also act as a catalyst in promoting
agglomeration of particulate matter. Particles down to
the sub-micron range have been found to agglomerate to
particles of 10 microns and greater.
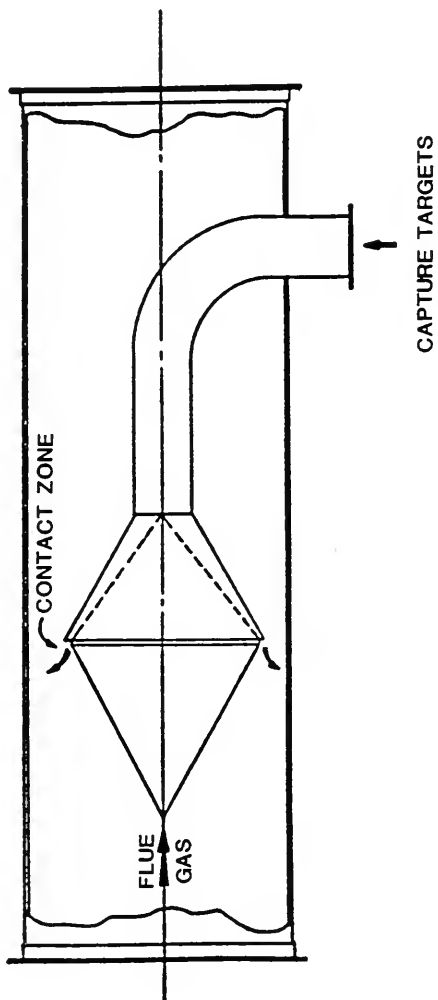
Figure 6-10
DRY SCRUBBER

A baghouse is placed downstream of the dry venturi to catch the particles in the gas stream; it removes 95 to 99% of the particulate matter exiting the incinerator. It is estimated that the use of an ESP in lieu of a baghouse would result in particulate removal efficiencies in excess of 90% with either dry lime or lime slurry injection into the gas stream.

6.2.2.6 Odour Control

Techniques for odour control for emissions from equipment, systems, and processes associated with incineration systems are normally one of the following:

°   Fume incineration (afterburner)
°   Packed tower (absorber)

Other techniques that have been used for incinerator odour control with varied records of success include the following:

°   Catalytic oxidation
°   Absorption
°   Adsorption

These techniques are discussed below.

Burning is the ultimate odour control technique. Most odour-forming compounds are organic in composition. When oxidized or burned, they form carbon dioxide, water vapour, and other innocuous compounds, destroying the odour in the process. For most organic compounds, a temperature of 760°C (1400°F) maintained for a period of at least 0.5 seconds will be satisfactory for complete destruction. Complex organic molecules, such as phenols, require higher temperatures and retention times for effective destruc-

tion. In all cases, thermal destruction of any compound also requires effective mixing, or turbulence, within the furnace to ensure that the temperature/combustion requirements are met throughout the waste.

Separate fume incinerators are often used for odour destruction when other techniques are not effective, or when these odourous gases cannot be fed to the incinerator for destruction.

Fume incinerators (direct flame and catalytic units) are discussed in Chapter 4.

In absorption, the odourous constituent is absorbed into a solution by either chemical bond or solubility. In the case of solubility, an odourous gas may be absorbed by a liquid; however, if the odourous component of the gas does not condense and dissolve, the odourous gas may eventually be released.

Chemical absorption is generally an oxidative process. Many odours are unburned (unoxidized) hydrocarbons. By mixing or scrubbing with chemicals that have the ability to release oxygen (such as potassium permanganate, sodium hypochlorite, or chlorine dioxide), the odourous constituent can be effectively oxidized and lose its odour.

Packed towers, such as the one shown in Figure 6-11, are commonly used for the absorption process. Odorous gas enters the bottom of the tower and rises through a bed of packing. Liquid is injected at the top of the tower and the falling liquid wets the packing, providing effective contact and mixing between the odourous gas and the scrubbing liquid. The liquid, which contains the chemical oxidizer, can be collected at the base of the tower and recirculated back through the system.
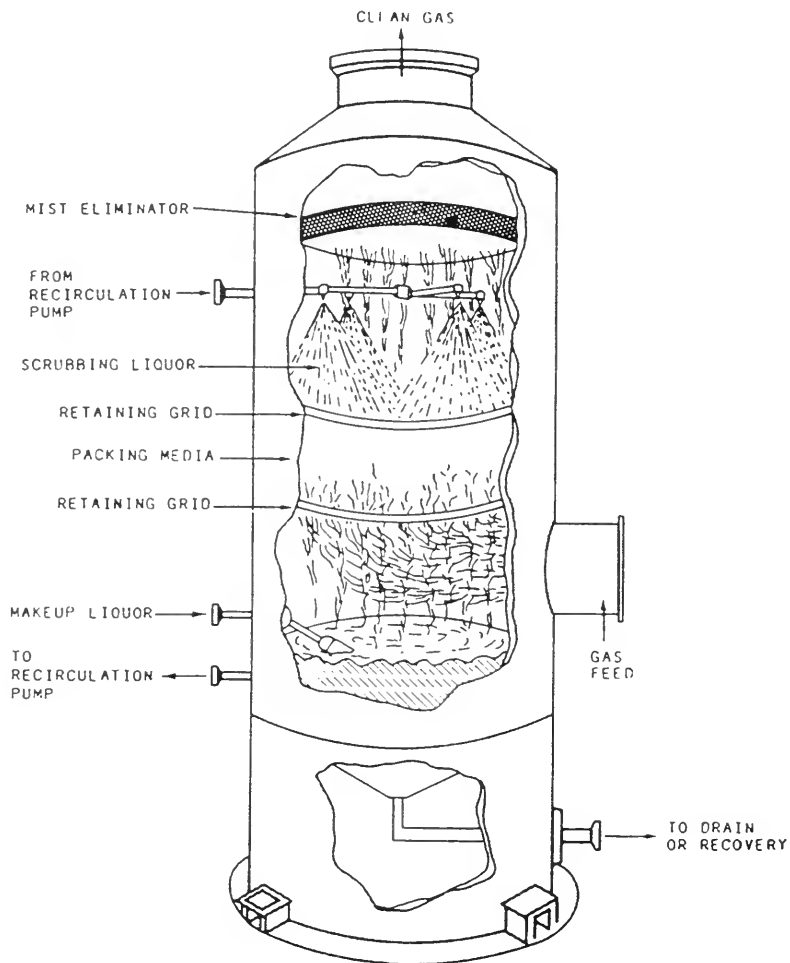
Figure 6-11
PACKED TOWER

These systems are relatively inexpensive from a capital investment standpoint. They also allow for the introduction of any scrubbing liquid or chemical. This feature is important because the choice of the proper chemical for odour destruction may require the use of a series of different compounds, eliminating ineffective ones until the chemical additive providing effective odour control is found.

Besides chemical oxidation, a number of odourous compounds can be altered, forming non-odourous compounds or forming other non-offensive odourous compounds by the addition of non-oxidative chemicals. One technique often used is the addition of caustic soda or a mild acid to scrubbing water. This changes the chemical nature of the odour, not necessarily oxidizing it, resulting in an acceptable discharge. Of course, the effectiveness of this procedure is a function of the nature of the odour, its constituent analysis, and its characteristics.

A number of materials have the physical property of high adsorptive capacity, i.e., the ability to adsorb or attract gases to their surfaces. Adsorptive media commonly used include activated carbon, silica gel, aluminum oxide, and magnesium silicate. The particles of each of these materials have extremely high surface area-to-weight ratios, providing high retentive capacity.

Activated carbon is the most widely used adsorbent. One reason for its popularity is that it has a low affinity for moisture. Moisture will not compete with contaminants in searching out the carbon surface. Other adsorbents will attract moisture and will have, therefore, a short useful life in wet-gas environments. Over a period of time, these other adsorbents can lose their effectiveness by picking up the moisture present as humidity in the air.

(Note that moisture particles present in a gaseous stream will reduce the effectiveness of a carbon filter to adsorb gaseous organic contaminants because of the physical blockage caused by the relatively large water particles.)

An important property of adsorbent materials is their ability to be regenerated. Normally, under the application of heat, the contaminant will be released and the adsorbent will be reactivated for reuse. Reactiviation may also require sparging of the spent adsorbent with steam to maximize its particulate surface area.

6.2.3   Selecting Appropriate Emissions Control
         Technology

Several important factors govern the selection of a system and equipment for controlling incinerator emissions, primarily regulatory requirements and utility availability; the nature of the waste stream, of course, must also be considered.

6.2.3.1 Regulatory Requirements

The first step in selecting an emissions control system is to examine the impacts of the relevant federal and provincial statutory requirements, as discussed in Chapter 2 including policies 01-01 and 01-03 which relate to combustion and air pollution control for refuse incinerators.

6.2.3.2 State-of-the-Art Control

The state-of-the-art control (SOAC) for incineration systems is a function of the nature of the waste stream and the type of incinerator used. SOAC is continually changing as new designs are developed and new equipment and

processes become available. Examples of SOAC for selected
equipment follow:

°   For mass burn refuse incinerators SOAC appears to be a
      dry scrubber followed by a fabric filter.

°   For industrial incinerators (rotary kiln application
      included) SOAC appears to be water quenching (includ-
      ing alkali) followed by a dry scrubbing system.

°   SOAC for sewage sludge disposal in multiple hearth or
      fluid bed incinerators appears to be a venturi scrub-
      ber followed by an impingement tray scrubber.

°   For controlled air incinerators burning paper waste,
      SOAC appears to be a fabric filter (baghouse).

In the United States and Europe dry scrubbing systems have
been found to be SOAC for refuse incinerators. Table 6-3
lists selected standards and/or policy requirements for
emissions based on Best Available Control Technology
(BACT).

6.2.3.3 Utility Availability

A wet-control device uses a relatively large quantity of
water for effective operation. If water is not available,
a wet device cannot be used, regardless of other consider-
ations.

In addition to a supply of water, wet-scrubbing systems
require water at a low enough temperature for effective
cooling of the gas stream. It is often desirable to
reduce the temperature of the gas exiting the stack, and
the use of relatively cool water may be necessary.

Table 6-3

Emission Standards Using BACT For Selected Locations

	CONNECTICUT	PENNSYLVANIA	NEW YORK	MICHIGAN	MASSACHUSETTS	CALIFORNIA	WEST GERMANY	SWEDEN	DENMARK
PARTICULATES	0.015 gr/dscf @ 12% CO_2	35 mg/Nm³ (0.015 gr/dscf) @ 7% O_2	50 mg/Nm³ (0.02 gr/dscf) @ 12% CO_2	35 mg/Nm³ (0.015 gr/dscf) @ 12% CO_2	Best Available Control Tech. (BACT) required (default max. 60 mg/Nm³ [0.03 gr/dscf])	0.01 gr/dscf @ 12% CO_2 (1)	50 mg/Nm³ (0.02 gr/dscf) stricter "state" limits, e.g. 0.013 often apply.	Emission "goal" 20 mg/Nm³ (0.01 gr/dscf) (2)	New "guideline" 40 mg/Nm²3 (0.017 gr/dscf) (3)
HCl	90% reduction	90%	90% or 50 ppmv	90%	No statewide limit; specific limits for acid gases are set on a case by case basis in the permitting process.	30 ppmv Use of wet or dry scrubbers is required.	50 mg/Nm³	60 ppmv (100 mg/Nm³) BACT required.	60 ppmv (100 mg/Nm³)
SO_2	0.32 lb/10⁶ Btu	None	"Acid Precip" New SO_2 limits see 6NYCRR 255-1	86 ppmv	Dry scrubbers are required by BACT rule.	30 ppmv	200 mg/Nm³	30 mg/Nm³	30 mg/Nm³ 3
NO_x	0.6 lb/10⁶ Btu	None	None	311 ppmv		(as NO_2) 140-200 ppmv	None	None	None
CO	CO/CO_2 ratio of 0.002	100 ppmv as 4-day avg.	"combustion Index" of 99.5% (1)	113 ppmv as 24-hr. avg. (over 3 hr.avg]	BACT	400 ppmv	100 mg/Nm³	None	None
DIOXINS measured as 2,3,7,8-TCDD	No Limit	No Limit	No Limit	Total PCDD 0.52 µg/Nm³ PCDF 0.5 µg/Nm³	No Limit (2)	No Limit	No Limit	Existing plants 0.5-2.0 ng/Nm³ New plants: 0.1 ng/Nm³	All facilities: 1.0 ng/Nm³

1. The combustion Index (CI) is defined as follows with CO and CO_2 as carbon monoxide and carbon dioxide concentration in the exhaust: $CI = \dfrac{CO_2}{CO_2 + CO} \times 100$

2. Massechusetts enforces the following ambient standards for dioxin: 2.2 pg/m³ gaseous, 1.1 pg/m³ particulate.

A conventional electrostatic precipitator will not need a supply of water for operation, but a wet ESP will have a liquid discharge that must be cleaned prior to disposal. The sewerage requirement may be a limitation on system selection. If a discharge cannot be fed directly to an existing sewer, the cost of treating it may be prohibitive.

6.2.3.4 Predicting Performance

The collection efficiency of a control device is specific to the particular equipment in question, and usually varies from one manufacturer to another. Listed data on system efficiencies can be used to obtain a reasonable estimate of system performance and can be useful in system selection.

Table 6-4 compares the average removal efficiencies for individual gaseous contaminants of various types of control equipment. The relatively high removal of HCl is a function of the water circulated within the indicated device and the gas-to-water contact efficiency.

Table 6-5 lists average particulate removal efficiencies of control equipment as a function of particle size. Below one micron, which is not included within these data, removal efficiency of all but the electrostatic precipitator will show a substantial decrease.

Table 6-4
Average Removal Efficiencies of Air Pollution Control Systems
(Percent)

System Type	Particulate		Hydrogen Chloride	Volatile Metals
	Mineral	Combustible		
None (settling chamber)	20	2	0	2
Dry Expansion Chamber	20	2	0	0
Spray Chamber	40	5	40	5
Wetted Wall Chamber	35	7	40	7
Wetted Close-Space Baffles	50	10	50	10
Mechanical Cyclone (dry)	70	30	0	0
Medium Energy Wet Scrubber	90	80	95	80
Electrostatic Precipitator	99	90	0	90
Fabric Filter	99.9	99	0	99

NOTES:

1. Removal efficiencies for carbon monoxide and hydrocarbons are zero for the above systems.

2. Combustible particulate and volatile metals are assumed to be primarily < 5μ mean diameter.

SOURCE: K. Akita, Journal of Polymer Science, Volume 5, Page 833.

Table 6-5
Average Particulate Removal Efficiencies
of Gas Cleaning Equipment

Equipment Type	Collection and Removal Efficiency		
	50μ	5μ	1μ
Inertial Collector	95	16	3
Medium Efficiency Cyclone	94	27	8
High Efficiency Cyclone	96	73	27
Impingement Scrubber	98	83	38
Electrostatic Precipitator	>99	99	86
Wet Electrostatic Precipitator	>99	98	92
Flooded Disc Scrubber, Low Energy	100	99	96
Flooded Disc Scrubber, Medium Energy	100	99	97
Venturi Scrubber, Medium Energy	100	>99	97
Venturi Scrubber, High Energy	100	>99	98
Shaker Type Fabric Filter	>99	>99	99
Reverse Jet Fabric Filter	100	>99	99

SOURCE: J. Starimand, Chemical Engineering (London),
        Volume 194, Page 310

It is usually not possible to obtain data on particle size
distribution without performing extensive tests on the
equipment in question burning the fuel (waste) in
question.

If this information were available, selecting a control
system would be a simple exercise of matching particle
size input to the known incinerator particulate removal
efficiency.

Normally, the actual selection of a control system and
system operating parameters requires an "educated guess"
on the part of the engineer and the manufacturer because
the precise particle size distribution is not known.
Tables 6-6 and 6-7 list particle size distribution for
tests on two incinerators, one burning sewage sludge and
the other firing refuse.

Table 6-6
Sewage Sludge Incineration Airborne Particle Size

	% By Weight Less Than Indicated Size	
	Location a	Location b
Particulate Loading		
g/dry m^3	4.30	0.02
kg/h	98.48	0.67
g/wet kg	23.25	0.16
Size Distribution, microns		
18.7	37.9	100.0
11.7	30.6	98.0
8.0	16.4	94.9
5.4	6.6	93.4
3.5	2.6	92.8
1.8	1.6	83.3
1.1	0.9	67.7
0.76	0.1	54.6

(a) Measured at incinerator outlet, without controls,
burning 102 tonnes/day wet sludge cake

(b) Measured after venturi scrubber with a total pressure
drop of 7.47 kPa

SOURCE: C.R. Brunner, INCINERATION SYSTEMS: Selection and
Design, Van Nostrand Reinhold, 1984

Table 6-7
Refuse Incineration (Waterwall) Airborne Particle Size

	Unit	
	255 tonnes/day	122 tonnes/day
Particle Specific Gravity, kg/m^3	43.25	60.39
Particle Bulk Density, kg/m^3	494.97	150.57
Loss on Ignition @ 760°C	8.20	30.40
Size Distribution, % By Weight Less Than Indicated Size: Microns		
30	40.4	50.0
20	34.6	45.0
15	31.1	42.1
10	26.8	38.1
8	24.8	36.3
6	22.3	33.7
4	19.2	30.0
2	14.6	23.5
Particulate Emission Rate:		
g/kg	10.98	4.06
kg/h	116.50	20.68

NOTE: Measurements made at incinerator exit, prior to any
        control equipment.

SOURCE: C.R. Brunner, INCINERATION SYSTEMS: Selection and
         Design, Van Nostrand Reinhold, 1984.

6.2.3.5   Selection

As noted above, many factors are to be considered in
selecting the appropriate control device. The nature of
the waste stream is a factor, as well as the type of
incinerator equipment that is used. In addition, regula-
tory constraints must be considered.

6.2.4   Air Toxics Removal

Incinerator systems which meet the requirements of Policy
01-01 and 01-03 will minimize the formation of organics
including toxic chlorinated compounds, and minimize their
emission into the ambient air. Control systems which

achieve the requirements of this policy will also reduce
the emissions of metals (including beryllium, arsenic,
cadmium chromium, mercury, nickel, lead, selenium, anti-
mony and zinc) and metallic compounds.

6.3   SOLID WASTE

6.3.1   Solid Residues

6.3.1.1 Quantities/Characteristics

Ash produced from incineration is primarily inorganic and
can be classified into the categories of fly ash and bot-
tom ash. Fly ash is entrained in exhaust gases leaving
the incinerator and is usually captured in air pollution
control equipment. Bottom ash is that portion that
remains in the combustion chamber after incineration and
is normally associated with inerts.

Ash composition varies greatly and depends on the composi-
tion of the waste being incinerated. In municipal refuse
incineration, solid materials not susceptible to oxidation
(i.e., ceramic or glass) constitute most of the ash;
however, depending on the type of incinerator and its
efficiency, the ash might also contain unburned waste
feed.

The relative proportion of fly ash to bottom ash depends
on the waste composition and on the incinerator design and
operation. When liquid or gaseous wastes are incinerated,
no bottom ash and relatively little fly ash result.
However, more ash is produced by liquids derived from
complex chemical processes containing inerts or from

blending procedures that create incompatible reactions which produce inerts.

When solid wastes are incinerated, both bottom ash and fly ash result. The bottom ash from incineration of sewage sludge is approximately from 15 to 20% of the total mass feed. Refuse incineration can produce ash in varying amounts depending on the waste material burned, but ash content normally ranges from 5 to 15% of the total mass feed.

The bottom ash contains primarily inorganic and carbonaceous compounds. Usually less than 3% of the total weight of carbonaceous compounds is made up of trace compounds, including heavy metals.

6.3.1.2 Wet and Dry Solids

Ash can be removed by either wet or dry methods. Fly ash, along with other gaseous pollutants, should be removed by an air pollution control system. If a wet system is used, fly ash and gases will form a sludge if allowed to concentrate in the scrubber. Normally, however, scrubber blowdown will control the solids so that sludges do not form. Again, the composition of the scrubber wastewater stream depends directly on the wastes being incinerated. Blowdown is usually mixed with other liquid waste streams for further treatment and disposal.

If a baghouse or an electrostatic precipitator are used to remove fly ash, a dry solid residue results.

6.3.2 Solid Waste Handling

6.3.2.1 Dry Versus Wet Handling

Bottom ash is discharged continuously or periodically. In
a continuous system, the ash discharges into a dry ash bin
or wet well. From this point, it is transferred to a con-
tainer or truck, usually by means of drag conveyors.
Lighter ash is collected at the outlet of the incinerator
and is normally directed into a closed system.

Classification of the ash residues as hazardous or nonhaz-
ardous should be determined using the leachate extraction
procedure in Regulation 309.

Fly ash collected in a wet scrubber leaves the system with
the scrubber blowdown and is further treated in a liquid
waste treatment system.

Figure 6-12 is a schematic of a solid waste incineration
process including bottom ash collection and fly ash scrub-
bing system.

6.3.2.2 Sludge Dewatering

Incineration operations may generate sludge from water/
wastewater treatment and ash sludge if a wet ash removal
system is employed. Sludges are normally dewatered to
reduce the volume before landfilling. Sludge dewatering
is usually accomplished by gravity.

6.4   LIQUID WASTES

6.4.1   Wastewater Sources

Figure 6.12 shows an incineration process with emissions
treatment and disposal options.

6.4.1.1   Wet Scrubbers

Gaseous pollutants and particulates resulting from incin-
eration can be captured by one of the following wet meth-
ods: (1) water in a quench tower, (2) water in a scrubber,
or (3) alkaline liquid in a scrubber. The wet bottom
quench tower, used mainly to lower the flue gas tempera-
ture, also functions as a scrubber by removing a small
amount of particulate and gaseous pollutants from the
incinerator exhaust. Water scrubbers are used for captur-
ing the majority of gaseous pollutants in the combustion
gas prior to atmospheric discharge. An alkaline scrubber
is used to further reduce gaseous components that were not
removed in the quench tower or water scrubber.

A water quench tower is used when a waste heat recovery
system is not part of the incinerator design package. In
addition to lowering the flue gas temperature, it operates
like a single-pass scrubber. The quench tower effluent
characteristics are highly variable, depending on inciner-
ator operation, waste material being incinerated, quench
tower feed rates, and scrubbing efficiency of the tower.

A wet scrubber with water as a medium is normally used
downstream of the waste heat recovery system or water
quench tower. Water scrubber effluents are quite differ-
ent from quench tower effluents. Normally, scrubbers are
recirculated systems with blowdown that controls the
amount of total dissolved solids (TDS). The blowdown rate
is variable, depending the water feed rate and on the

6-53
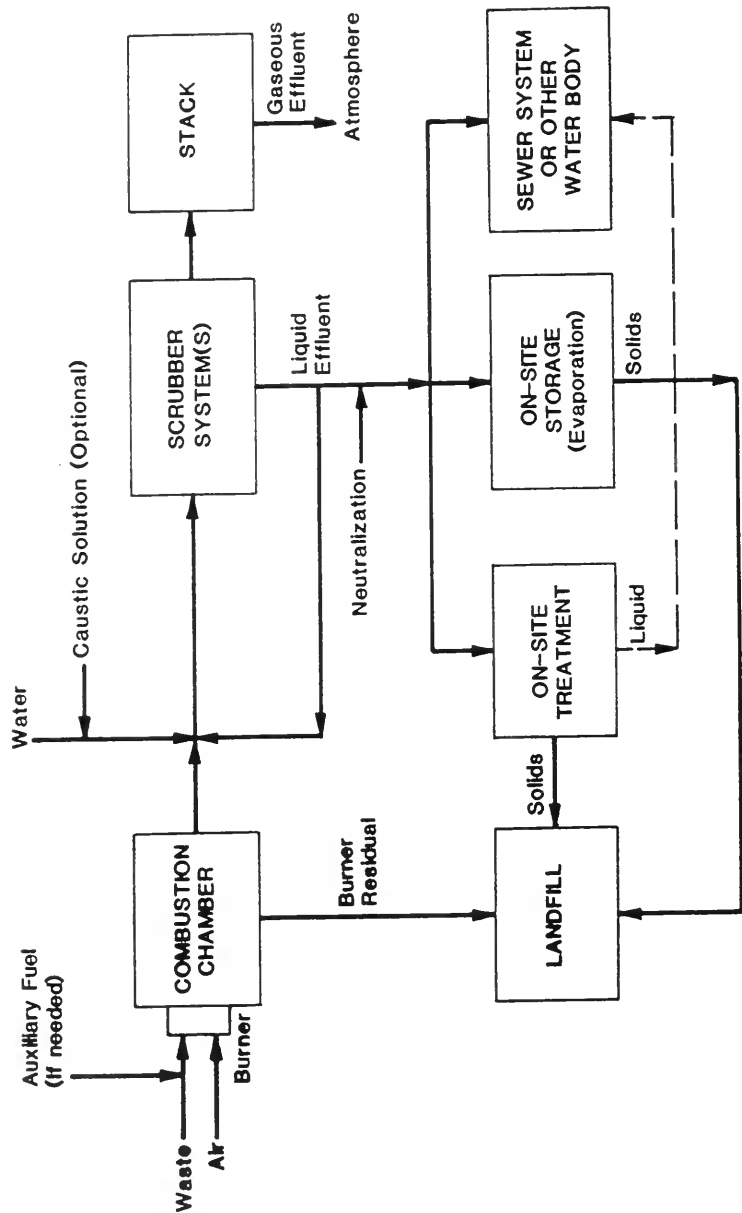
Figure 6-12

INCINERATION PROCESS WITH EMISSIONS
TREATMENT AND DISPOSAL OPTIONS

amount of acidic gases in the incinerated waste stream.
Generally, blowdown occurs when the TDS content reaches
approximately 3%. Water scrubber effluents are usually
acidic in nature and may contain trace quantities of
incinerated waste constituents and/or organics. Acidic
effluents may be further processed for acid recovery or
may be treated as a liquid waste. As a waste liquid, the
stream may or may not be neutralized prior to mixing with
other waste streams.

Alkaline (caustic) scrubbers are often used in conjunction
with quench towers and/or water scrubbers. This type of
scrubber would be used to remove acidic gases and other
residual combustion products not captured in the water
scrubbers. Alkaline scrubbers are usually recirculated
systems with blowdown. Scrubber effluents are generally
alkaline since the scrubbing medium is used in excess to
ensure that all noxious substances in the exhaust gas are
removed prior to being discharged to the atmosphere.
Alkaline scrubber effluents may or may not be neutralized
prior to mixing with other liquid waste streams.

6.4.1.2 Other Wastewater Sources

Other wastewater sources include waste heat recovery boil-
er blowdown, raw water treatment wastewaters, cooling
tower blowdown, sludge dewatering liquid wastes, site run-
off, and drainage from waste storage areas. All of these
wastewaters are typically rich in suspended and dissolved
solids and are of similar chemical makeup. Some streams
may contain hazardous compounds and/or organics. Depend-
ing on the overall wastewater treatment program, it may be
desirable to (1) separate some streams from the total
combination of streams in order to treat them separately
prior to disposal or (2) combine them with other waste-
water streams.

Chapter 7
REFERENCES AND BIBLIOGRAPHY

GENERAL

Anon., "Municipal Refuse: Using Society's Wastes To Fuel Large Steam Generators," Heat Engineering, Vol. 50, No. 5, 1982, pp. 78-81.

Anon., "Turning Sludge Into a Boiler Fuel," Marine Engineers Review, 1983, pp. 16-20.

Arnold, G.D., "Disposal of Toxic Wastes with Energy and Material Recovery," Management and Conservation of Resources, Institute of Chemical Engineers, Rugby, England, 1982.

Bird and Hale Ltd., Clarke Derszko and Associates Ltd., L.S. Love and Associates Ltd., Municipal Refuse Statistics for Canadian Communities of Over 10,000 (1976-1977), prepared for Environmental Protection Service, Environment Canada, 1979.

Black, Myron W., and Swanson, Jon R., "Destruction of PCBs in Cement Kilns," Pollution Engineering, Vol. XV, No. 6, 1983, p. 50.

Bogtstra, A.N., "Incineration of Industrial Exhaust Gases," Environmental Pollution Management, Vol. 10, No. 1, 1980, pp. 16-19.

Borgese, D., "Technical & Economic Overview on Use of Solid Waste in Power Plant Boilers," presented at the National Incinerator Conference of the American Society of Mechanical Engineers at Boston, MA (May 23-26, 1976).

Boughner, B.T., "Kraft Pulping in Canada - Recovery Boilers and Auxiliaries," presented at the Canadian Pulp & Paper Association Technical Section 71st Annual Meeting (1985).

Brooks, C., Energy From Municipal Waste: State-of-the-Art and Emerging Technologies - Workshop Proceedings, DOE Report No.: CONF-831151 (February 1984).

Brooks, C., Proceedings of the Waste-to-Energy Workshop on Small-Scale Combustion Systems, DOE Report No.: CONF-830717 (February 1984).

Brunner, C., Design of Sewage Sludge Incineration Systems, Noyes Data Corporation (1980).

Brunner, C., and Schwartz, S., Energy and Resource Recovery From Waste, Noyes Data Corporation (1983).

Brunner, C., <u>Incineration Systems</u>, Van Nostrand Reinhold Co. (1984).

Brunner, C., <u>Hazardous Air Emissions From Incineration</u>, Chapman and Hall (1985).

Carter, R.V., <u>Disposal of Toxic Chemicals & Medical Wastes by Incineration</u>," presented at the 71st Air Pollution Control Association Annual Meeting and Exhibition at Houston, TX (June 25-30, 1978).

Castaldini, C., Mason, H.B., DeRosier, R.J., and Unnasch, S., "Field Tests of Industrial Boilers Cofiring Hazardous Wastes," <u>Hazardous Waste</u>, Vol. 1, No. 2, 1984, pp. 159-166.

Castaldini, C., Unnasch, S., and Mason, H.B., <u>Engineering Assessment Report - Hazardous Waste Cofiring in Industrial Boilers, Volume 1 Technical Results</u>, EPA-600/2-84/177a (November 1984).

Castaldini, C., Willard, H.K., Wolbach, C.D., and Waterland, L.R., <u>Technical Overview of the Concept of Disposing of Hazardous Wastes in Industrial Boilers</u>, EPA-600/2-84/197 (December 1984).

Chadbourne, J.F., and Helmsteller, A.J., "Burning Hazardous Waste in Cement Kilns," <u>Proceedings of the Annual Meeting of the Air Pollution Control Association</u>, 1983.

Chamberlain, C.T., "Waste Heat Recovery From Combustible Wastes," <u>Management and Conservation of Resources</u>, Institute of Chemical Engineers, Rugby, England, 1982.

Chang, T.J., McCourt, J.E., and Gardner, R.B., <u>Field Investigation and Facility Review of Eight Modular Starved-Air Heat Recovery Incinerator Systems</u>, Naval Civil Engineering Laboratory, Report No.: NCEL-CR-85.001 (October 1984).

Chisamore, G.C., "Waste to Energy Systems," presented at the 31st Ontario Industrial Waste Conference at Toronto, Ontario, Canada (June 17-20, 1984).

Clennell, W.A., "Evaluation of Incineration as an Energy Recovery Process," <u>Reuse of Solid Waste, Proceedings of a Conference on the Practical Implications of the Reuse of Solid Waste</u>, Thomas Telford Ltd., London, England, 1982, pp. 57-63.

Coomaraswamy, M., Haley, C.A.C., and Giles, P.E., "Use of Solid Wastes as a Fuel in the Cement Industry," <u>Reuse of Solid Waste, Proceedings of a Conference on the Practical Implications of the Reuse of Solid Waste</u>, Thomas Telford Ltd., London, England, 1982, p. 33-38.

Cottrell, H.L., and Faith, W.A., "Method and a System for Incinerating Combustible Wastes," U.S. Patent Office Gazette, Vol. 1004, No. 1, 1981, p. 78.

Tenth Annual Report of the Council of Environmental Quality, Municipal Solid Waste, December 1979.

Crimmins, J., Khinkis, M., Kung, V., Korenberg, J., and Reider, C., "Development and Commercialization of an Efficient Cyclonic Incinerator for Wastes," Symposium Papers - Energy From Biomass and Wastes VIII, Institute of Gas Technology, Chicago, IL, 1984, pp. 385-432.

Dodds, J., Scrap Tire Fuel for Cement Kilns, DOE Report No.: CONF-8410167-SUM (October 1984).

Duckett, E.J., and Weiss, D., "RDF as a Kiln Fuel," Proceedings of the 1980 National Waste Processing Conference, ASME, 1980.

Dunn, K.S., "Incineration of Toxic and Dangerous Wastes," Environmental Pollution Management, Vol. 12, No. 1, 1982, pp. 14-18.

Dunn, K.S., "Incineration of Toxic Industrial Wastes - Environmental Success or Failure," Environmental Pollution Management, Vol. II, No. 1, 1981, pp. 12-16.

Erlandsson, Kjell I., "Co-incineration/Energy Recovery of Liquid and Solid Wastes," Pollution Engineering, Vol. XV, No. 4, 1983, p. 36.

Fernandes, J.H., "Burning of Wastes as Fuels in Industrial Boilers," presented at the 66th Annual Meeting of the Air Pollution Control Association at Chicago, IL (June 24-28, 1973).

Freeman, H., "Hazardous Waste Incineration," Hazardous Waste Management, 1981, pp. 59-70.

Gregory, Robert C., "Cost & Feasibility of Waste Heat Recovery From Waste Incineration," presented at the RCRA and the Clean Air Act Technical Conference of the Air Pollution Control Association at Wilmington, DE (April 18-19, 1983).

Guildford, N.G.H., "Tricil's New Incineration Plant and the Company's Experience With the Hearing for the Project," Proceedings of the 29th Ontario Industrial Waste Conference, Ontario Ministry of the Environment, Ontario, Canada, 1982, pp. 203-226.

Haley, Colin A.C., and Chatterton, Michael H., "Use of Solid Wastes as a Fuel in the Cement Industry in the UK," presented at the 1984 Annual Meeting of the American Institute of Chemical Engineers at San Francisco, CA (November 25-30, 1984).

Harrington, E.S., Holton, G.A., and O'Donnell, F.R., "Initial Emission Assessment of Hazardous-Waste-Incineration Facilities," presented at the UCC-ND and GAT Environmental Protection Seminar at Gatlinburg, TN (April 5, 1982).

Harrison, J.W., White, J.B., and King, W.J., Assessment of Hazard Potential From Combustion of Wastes in Industrial Boilers, EPA-600/7-81-108 (July 1981).

Hasselriis, F., Thermal Systems for Conversion of Municipal Solid Waste, Volume 4, Burning Refuse-Derived Fuels in Boilers: A Technology Status Report, NTIS, Springfield, VA (1983).

Heat Recovery Incinerator - Equipment Selection and Plant Layout for Safety, Human Engineering & Maintainability, Naval Civil Engineering Laboratory, Report No.: NCEL-CR-85.002 (October 1984).

Helmstetter, A.J., and Higgins, G.M., "Evaluation of Hazardous Waste Incineration in a Dry Process Cement Kiln," presented at the Eighth Annual Research Symposium on Land Disposal, Incineration and Treatment of Hazardous Waste of the Office of Research and Development, U.S. Environmental Protection Agency (March 8-10, 1982).

Helt, J.E., and Myles, K.M., Energy From Municipal Waste: Preliminary Assessment of External Combustion, DOE Report No.: ANL/CNSV-40 (December 1983).

Hovland, K., "Treatment of Industrial and Chemical Wastes by Incineration," presented at the 3rd International Congress on Industrial Waste Water & Wastes (February 6-8, 1980). The International Union of Pure & Applied Chemistry.

Hovland, Kim, "Corrosion Problems in Connection With Incineration of Municipal Solid Waste," New Energy Conservation Technologies and Their Commercialization Proceedings of an International Conference, Vol. 2, Springer Verlag, New York, NY, 1981.

Hughes, T.W., Peters, J.A., and Mournighan, R.E., "Monitoring of Pollutant Emissions From a Cement Kiln Fueled With Chlorinated Wastes," presented at the 8th Annual Research Symposium on Land Disposal, Incineration, and Treatment of Hazardous Waste of the Office of Research and Development, U.S. Environmental Protection Agency, (March 8-10, 1982).

Hunt, G.T., Wolf, P., and Fennelly, P.F., "Incineration of Polychlorinated Biphenyls in High-Efficiency Boilers: A Viable Disposal Option," Environmental Science & Technology, Vol. 18, No. 3, 1984, pp. 171-179.

Hunter, Eric, "Incineration of Liquid Industrial Waste," presented at the 33rd Canadian Chemical Engineering Conference at Toronto, Ontario, Canada (October 2-5, 1983).

Kawaoka, Keith E., Military Wastes-to-Energy Applications, Aerospace Corp., Report No.: ATR-80 (8374)-1 (November 1980).

Keitz, E., Vogel, G., Holberger, R., and Boberschmidt, L., Profile of Existing Hazardous Waste Incineration Facilities and Manufacturers in the United States, EPA, Industrial Environmental Research Laboratory, EPA-600/2-84-052 (February 1984).

Kiang, Y.H., and Metry, A., Hazardous Waste Processing Technology, Ann Arbor Science, Woburn, MA, 1982.

Klee, A.J., Calvert, S., and Englund, H.M. (Eds.), "Source Control-Municipal Solid Waste Incinerators," Handbook of Air Pollution Technology, John Wiley & Sons, Inc., New York, NY, 1984, pp. 513-550.

Kleinau, J.H., "Sludge Disposal by Combustion Offers Potential Energy Source," Pulp Paper, Vol. 55, No. 13, December 1981, pp. 141-143.

Large-Scale Commercial Combustion Systems for Producing Energy From Municipal Solid Waste, DOE Report No.: DOE/CS/24312-8 (February 1985).

Lauber, J.D., "Burning Chemical Wastes as Fuels in Cement Kilns, Journal of the Air Pollution Control Association, Vol. 32, No. 7, 1982, pp. 771-777.

Lauber, J.D., "Burning Chemical Wastes as Synthetic Fuels in Cement Kilns," presented at the 74th Air Pollution Control Association Annual Meeting at Philadelphia, PA (June 21-26, 1981).

Leege, P.B., "Paper Products Factory Waste Becomes Heat Instead of Landfill," Specifying Engineer, Vol. 47, June 1982, pp. 54-55.

Luca, R.O., "Refuse-Derived Fuel as a Partial Substitute for Normal Kiln Fuel in Portland Cement Manufacturing," presented at the American Concrete Institute Annual Convention at Toronto, Ontario, Canada (April 9-14, 1978).

MacDonald, L., "Waste Oil & Polychlorinated Biphenyls (PCB) as Kiln Fuels in Portland Cement Manufacturing," presented at the American Concrete Institute Annual Convention at Toronto, Ontario, Canada (April 9-14, 1978).

Manning, M.P., "Fluid Bed Catalytic Oxidation: An Underdeveloped Hazardous Waste Disposal Technology," Hazardous Waste, Vol. 1, No. 1, 1984, pp. 41-65.

McCormick, R.J., DeRosier, R.J., Capital and O and M (Operation/Maintenance) Cost Relationships for Hazardous Waste Incineration, EPA-600/2-84/175 (October 1984).

Miner, R.A., "Review of Sludge Burning Practices in Combination Fuel-Fired Boilers," 1982 Environmental Conference Proceedings, Technical Association of the Pulp & Paper Industry, pp. 119-130.

Monsanto Research Corporation, Engineering Handbook for Hazardous Waste Incineration, EPA Report No. MRC-DA 1090, 1981.

Niessen, W.R., "Incineration Is a Waste-Management Alternative," Water & Sewage Works, Vol. 127, No. 10, 1980, pp. 30-31, 49.

Oberacker, D.A., Hazardous Waste Incinerator Performance Evaluations by the United States Environmental Protection Agency, EPA, Hazardous Waste Engineering Research Laboratory, 1984.

Olexsey, Robert A., "Air Emissions From Industrial Boilers Burning Hazardous Waste Materials," presented at the 77th Air Pollution Control Association Annual Meeting at San Francisco, CA (June 24-29, 1984).

Olexsey, Robert A., Freeman, Harry K., and Mournighan, Robert E., "Hazardous Waste to Energy," presented at the 1985 American Society of Mechanical Engineers National Heat Transfer Conference at Denver, CO (August 4-7, 1985).

Ollman, Philip J. "Pyrolytic Incineration of Solid Waste for Energy Recovery," Advances in Energy Productivity (5th World Energy Engineering Congress), Fairmont Press, Atlanta, GA, 1982, pp. 299-302.

Oppelt, E.T., "Thermal Destruction Options for Controlling Hazardous Wastes," Journal of Civil Engineering, American Society of Civil Engineers, Volume 51, No. 9, 1981, pp. 72-75.

Penberthy, Larry, and Hotaling, Dennis, "Use of Electrically Heated Radiant Glass Furnace for Destruction of Hazardous Waste," Waste Management '82: Waste Isolation in the U.S. and Elsewhere, Technical Programs and Public Communications (Volume 1: General), Arizona Board of Regents, 1982, pp. 311-313.

Peterson, C., "Japanese, Europeans Lead in Waste-to-Energy Incineration," World Wastes, Vol. 28, No. 6, 1985, pp. 32-33.

Plumley, A.L., Llinares, Jr., V., and Roczniak, W.R., Cofiring of Refuse-Derived Fuel and Coal at Oak Creek, Volume 2 Boiler Slagging and Fouling Evaluation, Final Report, Combustion Engineering, Inc., Report No.: EPRI-CS-1983-V.2 (October 1982).

Porteous, A., "Municipal Waste Derived Fuels, Production Combustion and Environmental Aspects," Journal of Heat Recovery Systems, Vol. 4, No. 5, 1984, pp. 317-322.

Rasmussen, Mogens, "Energy From Waste: European Incinerating Technology," Commission of the European Communities Report EUR 7277, D. Reidel Publishing Co., Boston, MA, 1981, pp. 171-181.

Rickman, W.S., and Holder, Nadine D., "Circulating Bed Incineration of Hazardous Wastes," presented at the 1984 Summer National Meeting of the American Institute of Chemical Engineers, at Philadelphia, PA (August 19-22, 1984).

Robb, A.F., "Energy From Waste in a Cement Kiln," presented at the 31st Ontario Industrial Waste Conference, at Toronto, Ontario, Canada (June 17-20, 1984).

Rogers, H.G., and Scott Paper Company, "Firing of Waste Streams in Recovery Boilers," Technical Association of the Pulp & Paper Industry International Chemical Recovery Conference Proceedings, Book 2, 1985, pp. 281-287.

Ross, D.R., "Incineration of Containerized Hazardous Wastes," Industrial Wastes, Volume 29, No. 6, 1983, p. 13.

Ross, R.D., "Incineration - A Positive Solution of Hazardous Waste Disposal," presented at the American Chemical Society 178th Annual Meeting, (September 9-14, 1979).

Ross, Richard D., "Hazardous Waste Incineration: An Overview of Equipment Alternatives," Proceedings of the 2nd Annual Hazardous Materials Management Conference, at Phildadelphia, PA (June 5-7, 1984).

Ross, Richard D., "Incineration - A Tool for Hazardous Waste Management," Water Resources Symposium No. 10, Center for Research in Water Resources, Austin, TX, 1983, pp. 241-249.

Schoen, D.P., "Incineration of Hazardous Wastes," presented at the American Institute of Chemical Engineers 71st Annual Meeting at Miami Beach, FL (November 12-16, 1978).

Shaub, W.M., Containment of Dioxin Emissions From Refuse Fired Thermal Processing Units: Prospects and Technical Issues, National Bureau of Standards (NEL), Center for Fire Research, Report No.: NBSIR-84-2872 (April 1984).

Snellink, G., "Thermal Incineration of Waste Gases," presented at the 2nd European Symposium on Combustion of the Combustion Institute at Orleans, France (September 1-5, 1975).

Sneyd, R.J., and Mayrose, D.T., "Fluid Bed Incineration," Water to Sewage Works, Vol. 127, No. 9, 1980, pp. 38-45.

Sweet, W.E., Ross, R.D, and Vander Velde, G., "Hazardous Waste Incineration: A Progress Report," Journal of the Air Pollution Control Association, Vol. 35, No. 2, 1985, p. 138.

Sweet, W.E., Ross, R.D., and Velde, G.V., "Hazardous Waste Incineration: A Progress Report," Journal of the Air Pollution Control Association, Vol. 35, No. 2, 1985, pp. 138-142.

Sweet, Wileen E., and McCoy, Andrew J., "Co-incineration of High and Low Btu Wastes," presented at the American Institute of Chemical Engineers 1982 Summer National Meeting, at Cleveland, OH (August 29-September 1, 1982).

Thomas, Malcolm H., Heat Recovery From Boiler Economizers and Waste Incinerators, Fairmont Press, Inc., Atlanta, GA, 1981, pp. 11-12.

Tillman, D.A., "Fuels From Waste," Kirk - Othmer Encyclopedia of Chemical Technology, Volume 11, Wiley & Sons, 1980, pp. 393-410.

Travis, C.C., Health Risk of Hazardous Waste Incineration, DOE Report No. CONF-8410171-3 (1984).

Travaas, Knut, "Hazardous Waste Incineration in a Cement Kiln," Hazardous Waste Disposal (Proceedings of the NATO Committee on the Challenges of Modern Society Symposium), Plenum Press, New York, NY, 1983, pp. 201-214.

Tsang, Wing, and Shaub, Walter, "Chemical Processes in the Incineration of Hazardous Materials," Proceedings of the 182nd National Meeting of the American Chemical Society, Division of Environmental Chemistry, Vol. 21, No. 2, American Chemical Society, Washington, DC, 1981, pp. 45-47.

Turner, W.D., "Energy Recovery From Mass Burning of Municipal Solid Waste in Waterwalled Incinerators - Current U.S. Status," presented at the 6th Annual ASME Energy - Sources Technology Conference & Exhibition, at Houston, TX, 1983, pp. 103-111.

VanWambeke, Leopold, "Energy From Municipal Waste in the European Community," Commission of the European Communities Report EUR 7277, D. Reidel Publishing Co., Boston, MA, 1981, pp. 159-170.

Walls, T.B., Energy Recovery From Mass Burning of Municipal Solid Wastes, proceedings from Resource Recovery from Solid Wastes Conference, Miami Beach, Florida, May 1982.

Weitzman, L., "Cement Kilns as Hazardous Waste Incinerators," Environmental Progress, Vol. 2, No. 1, 1983, pp. 10-14.

Weitzman, Leo, "Using Cement Kilns as Hazardous Waste Incinerators - An Overview," presented at the American Institute of Chemical Engineers 1981 Annual Meeting, at New Orleans, LA (November 8-12, 1981).

Willey, C.R., and Weinberger, C.S., Demonstration Test of Refuse-Derived Fuel as a Supplemental Fuel in Cement Kilns, Maryland Department of Natural Resources, Annapolis, MD, 1985.

Wong, T.S., "Dioxin Formation and Destruction in Combustion Processes," presented at the 77th Air Pollution Control Association Annual Meeting at San Francisco, CA (June 24-29, 1984).

GOVERNMENT

Ontario Ministry of the Environment, Water Management Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment, November 1978, Revised May 1984.

Ontario Ministry of the Environment, Criteria for Incineration Design and Operation, Revised June 1974.

Ontario Ministry of the Environment and the Municipal Engineers Association, A By-Law to Control Industrial Waste Discharges to Municipal Sewers.

Ontario Ministry of the Environment, List of standards, ambient air quality criteria, tentative standards, guidelines, and provisional guidelines for air contaminants, September 1985.

Government of Ontario, Environmental Protection Act and Regulation 308.

Government of Ontario, Regulation 309 Under the Environmental Protection Act.

Government of Canada, Clean Air Act.

Government of Canada, Ambient Air Quality Objectives No. 1, 2, and 3 Under the Clean Air Act.

Government of Canada, Department of Fisheries and the Environment, Packaged Incinerators National Emission Guidelines.

Ontario Ministry of the Environment, Model Municipal Noise Control By-Law, Final Report, August 1978.

Associate Committee of the National Building Code, National Building Code of Canada 1985, National Research Council of Canada, Ottawa.

Appendix B
REGULATORY AND APPROVALS INFORMATION

o Relevant Sections of the National Building Code of
   Canada 1985, Concerning Incinerator Design

o Ministry Policies related to incineration

o Ministry of the Environment Head and Regional Offices

o Application for a Certificate of Approval (Air)

o Application for a Certificate of Approval for a Waste
   Disposal Site (Processing)

o Application for the Approval of Plans and Specifica-
   tions for the Construction of Works for the Collec-
   tion, Transmission, Treatment, and Disposal of
   Industrial Wastewater

Relevant Sections of the National Building Code
of Canada 1985
Concerning Incinerator Design

Section 3.5.2.5(1.) Service rooms containing an incinera-
tor must be separated from the remainder of the building
by a fire separation having a fire-resistance rating of at
least 2 hours. (2.) Service rooms containing an inciner-
ator shall not contain other fuel-fired appliances.

Section 3.5.2.7 Swing-type doors from an incinerator room
shall swing outward, except that the door shall swing
inward when the door opens on a corridor or any room for
assembly purposes.

Section 6.2.6.1 The design, construction, installation and
alteration of every indoor incinerator shall conform to
NFPA (National Fire Prevention Association) 82, "Incinera-
tors, Waste and Linen Handling Systems and Equipment".

Section 6.2.6.2 Every incinerator shall be served by a
chimney flue conforming to section 6.3 of the code.

POLICY TITLE	THE COMBUSTION OF REFUSE IN INCINERATORS	NO 01-01-01

Legislative Authority

the Environmental Protection Act
Regulation 308

Statement of Principles

This policy is designed to reduce contaminant emissions from incinerators by properly controlling the combustion process, and thereby to contribute to the protection of the environment. The policy establishes design and operating guidelines for application to new incinerators that burn one or a combination of domestic, commercial or non-hazardous solid industrial wastes.

Incinerators which meet the requirements of this guideline will achieve high combustion efficiencies, which will minimize the emissions of organics including toxic chlorinated compounds.

This policy refers only to the combustion process; additional emissions control and monitoring may also be required.

1. Incineration
    Temperature

    Refuse incinerators shall be designed for a minimum of at least 1100°C, and shall operate at a destruction temperature of not less than 1000°C.

Point of Contact   Director, Air Resources Branch

Effective Date

April 27, 1987

MOE 1428

2. Residence Time   Refuse incinerators shall be designed for a combustion gas residence time of not less than one second at 1000°C. This residence time is to be calculated from the point where most of the combustion has been completed and the incineration temperature fully developed.

           2.1   In multi-chamber incinerators this residence time is calculated from the secondary burner(s) flame front or final secondary air injection point(s).

           2.2   Where the furnace is one continuous space, such as in spreader stoker and single chamber mass burning designs, the location of the complete combustion/fully developed temperature point must be determined by an overall design review.

3. Oxygen Availability   Refuse incinerators shall be designed to provide not less than 6% residual oxygen in the flue gas exhaust from the incinerator or secondary chamber.

4. Turbulence and Mixing   Refuse incinerators shall be designed to provide a high degree of gas phase turbulence and mixing in the secondary combustion zone. Provisions shall include any combination of: appropriately located/directed air jets, changes of flue gas flow direction, baffling, and constriction of cross-sectional flue gas flow area.

5. Range of Operation   Refuse incinerators shall be designed to achieve the temperature, residence time, oxygen availability and turbulence requirements of this guideline over the complete expected range of values of the incinerator operating parameters, including:

-   feed rate, ultimate analysis, heating value, ash and moisture contents;

-   combustion air;

-   flue gas flow rates; and

-   heat losses.

6. Control and Monitoring

6.1   Control and monitoring systems on refuse
       incinerators shall be sufficient to ensure,
       and readily indicate and confirm, that the
       requirements of this guideline as well as
       other Ontario Ministry of the Environment
       standards, regulations and guidelines are
       consistently met. The controls and monitors
       shall be capable of readily signalling poor
       operation so that corrective action can be
       taken or the incinerator shut down.

6.2   Continuously monitored parameters shall
       include temperature(s), total hydrocarbons
       (or carbon monoxide), and opacity.
       Additionally oxygen, carbon dioxide,
       incinerator exhaust flue gas volume, hydrogen
       chloride, sulphur dioxide and nitrogen oxides
       monitoring may be required.

	NO
POLICY TITLE Air Pollution Control on Refuse Incinerators	01-03

Legislative Authority

The Environmental Protection Act
Regulation 309

Statement of Principles

State-of-the-art air pollution control systems shall be installed on all new incinerators which burn one or a combination of domestic, commercial or non-hazardous solid industrial wastes. This will reduce contaminant emissions from incineration systems and thereby contribute to the protection of the environment.

This policy will assist in the interpretation of Regulation 309, Sec. 9(4), and refers only to the air pollution control (APC) system and Policy 01-01 – the Combustion of Refuse in Incinerators. For discussion purposes, the Ministry has prepared an Interim Guideline for Control on Refuse Incinerators which further defines state-of-the-art requirements.

Point of Contact

Director, Air Resources Branch

Effective Date

November 2, 1987

MOE 1428

This interim guideline has been prepared for discussion purposes in interpreting the Ministry Policy on Air Pollution Control on Refuse Incinerators (01-03). The emission limits below have been developed based on available test data on existing installations. It will be reviewed and refined from time to time to reflect the anticipated increase in test result data from Ontario and other sources, and the anticipated development of control guidelines and/or regulations by the Canadian federal government and others.

1. Particulate Outlet Concentration

APC systems on refuse incinerators shall have a maximum guaranteed outlet particulate loading of not greater than 20 mg/Rm^3 @ 11% O_2 (milligrams per dry cubic metre normalized to 11% oxygen at a reference (R) temperature of 25°C and a reference pressure of 101.3 kPa).

2. Hydrochloric Acid (HCl) Removal

APC systems on refuse incinerators shall have a minimum guaranteed HCl removal efficiency of not less than 90%, or a maximum guaranteed HCl outlet concentration of 30 ppmv @ 11% O_2 (parts per million by dry volume normalized to 11% oxygen). (30 ppmv @ 11% O_2 is equivalent to about 50 mg/dry m^3 @ 25°C and 11% O_2).

3. Other Contaminants

Incinerator systems which meet the above requirements and Policy 01-01 will minimize the formation of organics including toxic chlorinated compounds, and minimize their emission into the ambient air. Control systems which achieve the requirements of this policy will also reduce the emissions of metals (including beryllium, arsenic, cadmium, chromium, mercury, nickel, lead, selenium, antimony and zinc) and metallic compounds, and acidic gases (including sulphur dioxide (SO_2), hydrogen bromide (HBr) and hydrogen fluoride (HF)).

4. Performance Testing and Monitoring

4.1 The guaranteed removal efficiency and/or outlet loadings as described above shall be demonstrated by performance test programs approved by the Air Resources Branch and, where applicable, by methods included in the Source Testing Code (Version #2, ARB-TDA-66-80) and any revisions and/or addenda thereto.

4.2 Performance tests shall be undertaken within 3 months of startup and thereafter on an annual basis. The performance test results shall be used to define the acceptable range of readings for continuous monitoring devices, and any exceedance of this acceptable range for any monitor shall be reported to the local District Office of the Ministry of the Environment.

27 October 1987

RE1527

MINISTRY OF THE ENVIRONMENT HEAD AND REGIONAL OFFICES
Environmental Approvals and Project Engineering Branch

Head Office

8th Floor 135 St. Clair Avenue, West
Toronto, Ontario
M4V 1P5
(416) 323-4397

Central Region

Toronto Regional and District Office
4th Floor 7 Overlea Boulevard
Toronto, Ontario
M4H 1A8
(416) 424-3000

Barrie District Office
12 Fairview Road
Barrie, Ontario
L4N 4P3
(705) 726-1730

Halton-Peel District Office
1226 White Oaks Boulevard
Oakville, Ontario
L6H 2B9
(416) 844-5747

Muskoka Haliburton District Office
Gravenhurst Plaza General Delivery
Gravenhurst, Ontario
P0C 1G0
(705) 687-3408

Peterborough District Office
139 George Street North
Peterborough, Ontario
K9J 3G6
(705) 743-3972

York Durham District Office
4th Floor 7 Overlea Boulevard
Toronto, Ontario
M4H 1A8
(416) 424-3000

Northeastern Region

Sudbury Regional and District Office
11th Floor 199 Larch Street
Sudbury, Ontario
P3E 5P9
(705) 675-4501

North Bay District Office
Northgate Plaza
1500 Fisher Street
North Bay, Ontario
P1B 2H3
(705) 476-1001

Parry Sound Sub Office
74 Church Street
Parry Sound, Ontario
P2A 1Z1
(705) 746-2139

Sault Ste. Marie District Office
445 Albert Street East
Sault Ste. Marie, Ontario
P6A 2S9
(705) 949-4640

Timmins District Office
83 Algouguin Boulevard West
Timmins, Ontario
P4N 2R4
(705) 264-9474

Northwestern Region

Thunder Bay Regional and District Office
P.O. Box 5000
3rd Floor 435 James Street South
Thunder Bay, Ontario
P7C 5G6
(705) 264-9474

Kenora District Office
P.O. Box 5150
808 Robertson Street
Kenora, Ontario
P4N 1X9
(807) 468-5578

Southeastern Region

Kingston Regional and District Office
P.O. Box 820
133 Dalton Avenue
Kingston, Ontario
K7L 4X6
(613) 549-4000

Belleville Sub Office
15 Victoria Avenue
Belleville, Ontario
K8N 1Z5
(613) 962-9208

Cornwall District Office
2nd Floor 4 Montreal Road
Cornwall, Ontario
K6H 1B1
(613) 933-7402

Ottawa District Office
2378 Holly Lane
Ottawa, Ontario
K1V 7P1
(613) 521-3450

Pembroke Sub Office
1000 Mackay Street
Pembroke, Ontario
K8B 1A3
(613) 732-3643

Southwestern Region

London Regional and District Office
985 Adelaide Street South
London, Ontario
N6E 1V3
(519) 661-2200

Chatham Sub Office
c/o Min. Agriculture & Food
P.O. Box 726
435 Grand Avenue West
Chatham, Ontario
N7M 5L1
(519) 354-2150

Clinton Sub Office
c/o Min. Agriculture & Food
P.O. Box 688
Clinton, Ontario
NOM 1L0
(519) 482-3428

Owen Sound District Office
1180 - 20 Street
Owen Sound, Ontario
N4K 6H6
(519) 371-2901

Sarnia District Office
Suite 109
265 North Front Street
Sarnia, Ontario
N7T 7X1
(519) 336-4030

Windsor District Office
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250 Windsor Avenue
Windsor, Ontario
N9A 6V9
(814) 254-2546

West Central Region

Hamilton Regional and District Office
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12th Floor, 119 King Street West
Hamilton, Ontario
L8N 3Z9
(416) 521-7652

Cambridge District Office
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400 Clyde Road
Cambridge, Ontario
N1R 5T8
(519) 623-2080

Welland District Office
637 - 641 Niagara Street North
Welland, Ontario
L3C 1L9
(416) 735-0431

REGIONS AND OFFICES
IN ONTARIO

Ministry of the Environment

Scale

25   0   25   50   75
        MILES

NORTHERN ONTARIO

Scale

100   0   100   200   300
            MILES

Regional Offices   ■ HAMILTON

District Offices   ● Sarnia

Map 23601.6
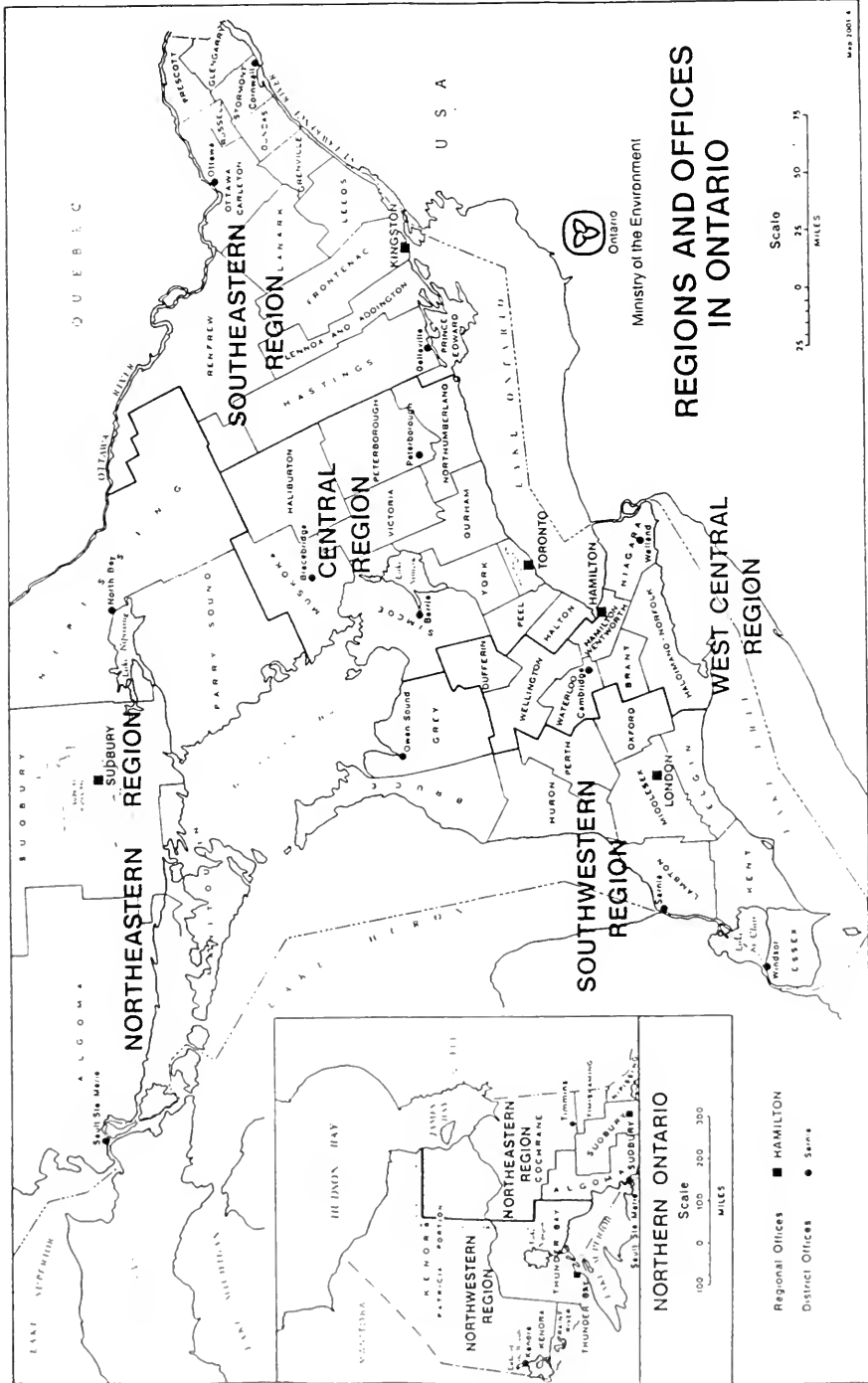
Ministry of the Environment Ontario Ministère de l'Environnement	**Application for a Certificate of Approval (Air)** *Demande de certificat d'autorisation (Air)*

In accordance with Section 8 of the Environmental Protection Act, the undersigned hereby applies for approval of plans and specifications for:

Conformément à l'article 8 de la Loi sur la protection de l'environnement, le soussigné, fait une demande d'approbation des plans et cahier des charges pour:

☐ Construction of a plant, factory, structure or manufacturing process as referred to in Section 8(1)(a) of the Act
La construction d'une usine, d'une installation, d'un appareil ou d'un procédé de fabrication tel qu'il en est fait mention à l'alinéa 8(1)(a) de la loi.

☐ Installation of emission control equipment as referred to in Section 8(1)(a).
L'installation d'un équipement de contrôle des émissions tel qu'il en est fait mention à l'alinéa 8(1)(a).

☐ A change of process, or increased production of a plant, referred to in Section 8(1)(b) consisting of:
Une modification de procédé ou une augmentation de débit de production tel qu'il en est fait mention à l'alinéa 8(1)(b) consistant en:

(Brief Description of Proposal as Related to this Application)
(Brève description de la proposition intéressant la présente demande)

_____

_____

_____

Applicant
Demandeur

Name
Nom

Telephone
Téléphone

☐ Owner
Propriétaire   ☐ Agent
Agent

Title
Titre

Company
Compagnie

Mailing Address
Adresse postale

1. Owner of Plant or Emission Control Equipment
Propriétaire de l'usine ou de l'équipement de contrôle des émissions

Telephone
Téléphone

Mailing Address
Adresse postale

2. Location of Plant or Emission Control Equipment
Adresse de l'usine ou de l'équipement de contrôle des émissions

City/Town
Ville ou canton

County
Comté

Street & No. or Lot and Concession
Rue et N° ou lot et concession

3. Plans and Specifications Prepared by
Plans et cahier des charges préparés par

Telephone
Téléphone

Mailing Address
Adresse postale

4. Description of manufacturing or production process with emphasis on sources of emission to be exhausted from the plant.
Description du procédé de fabrication ou de production en précisant les sources d'émissions produites par l'usine.

Additional Info. Enclosed?
Renseignements complémentaires ci-joints?

☐ Yes
Oui   ☐ No
Non

5. Production Data
Données de production

List principal materials used and products produced in the plant or part of the plant under consideration giving volume, weight, or quantity per day, week or other production period.

Énumérer les principaux matériaux utilisés ainsi que les produits fabriqués dans l'usine ou dans la partie de l'usine considérée, en indiquant les volumes, les poids ou les quantités par jour, par semaine ou pour toute autre période de production.

Raw Materials
Matières premières

Products
Produits

Current Production Level
Niveau de production actuel

Future Production Level and Date
Niveau futur de production et date

6. Industrial Operating Schedule
Horaire et calendrier d'exploitation

Hours per Day *Heures par jour*	Days per Week *Jours par semaine*	Weeks per Year *Semaines par an*	Shift Periods *Indiquer les quarts*

7. Control Equipment for Which Approval is Requested
Équipement de contrôle des émissions pour lequel une autorisation est demandée

	Number of Units *Nombre d'unités*	Pertinent Design Information (Including manufacturer's specifications and proposed operating data, if available.) *Renseignements pertinents sur la conception, y compris les caractéristiques fournies par le fabricant et, s'il y a lieu, les données d'exploitation proposées.*
Baghouse *Filtre à sacs*		
Cyclone *Cyclone*		
Scrubber *Dépoussiéreur*		
Electrostatic Precipitator *Électrofiltre*		
Paint Spray Booth & Controls *Cabine et commandes - pulvérisation de peinture*		Additional Info. Enclosed? *Renseignements complémentaires ci-joints?*
Other *Autre*		☐ Yes / *Oui* ☐ No / *Non*

8. Information and Drawings to be Submitted with the Application
Renseignements et dessins à présenter avec la demande

☐ A process-flow diagram and floor plan showing material flow and unit operations, including a material balance and heat balance where applicable. The points of emission and amounts involved for each contaminant must be identified on the process-flow diagram. In addition, the handling and storage of both raw materials and finished products must be shown as well as the disposition of waste products.

Un diagramme de circulation des matériaux et un plan d'étage indiquant la circulation des matériaux et le fonctionnement des unités, y compris un bilan matières et un bilan thermique s'il y a lieu. Les points d'émission et les quantités correspondant à chaque polluant doivent être indiqués sur le diagramme de circulation des matériaux du procédé de fabrication. En outre, les schémas doivent indiquer les opérations de manutention et d'entreposage des matières premières et des produits finis ainsi que les procédés d'élimination des déchets.

☐ A drawing indicating the location of proposed emission control equipment and all stacks or exhausters venting to the atmosphere including the dimensions of buildings.

Un dessin indiquant l'emplacement de l'équipement proposé de contrôle des émissions et de toutes les cheminées et tous les ventilateurs d'évacuation dégageant les émissions dans l'atmosphère, y compris les dimensions des bâtiments.

☐ A plot, roof and elevation plan, drawn to scale if possible, and showing emission points and distances to critical receptors (air intakes, openable windows, doors, etc.) on the attached building and on-property buildings. Indicate the distance from the points of emission to all property lines.

Un levé de terrain, un plan de structure du toit et une élévation, à l'échelle si possible, indiquant les points d'émission et leurs distances jusqu'aux récepteurs importants (prises d'air, fenêtres ouvertes/fermées, portes, etc.) du bâtiment et des autres bâtiments situés sur la propriété. La distance entre les points d'émission et toutes les limites de la propriété doit être indiquée.

☐ A plan showing the relation of the points of emission to off-property structures in the immediate neighbourhood. Include distance from the points of emission to the structure in question and the heights of the structure relative to the ground level elevation at the points of emission. The zoning designation and land use in the neighbourhood should also be indicated. "Immediate neighbourhood" means that area around the installation likely to be affected by airborne emissions from the installation.

Un plan indiquant la situation des points d'émission par rapport aux structures situées en dehors de la propriété mais dans le voisinage immédiat. Ce plan doit inclure les distances entre les points d'émission et la structure en question ainsi que les hauteurs de la structure par rapport au niveau du sol aux points d'émission. La désignation de zonage et l'utilisation des terres du voisinage doivent également être indiquées sur le plan. Par "voisinage immédiat", on entend la zone située autour de l'installation susceptible d'être affectée par les émissions en provenance de celle-ci.

☐ Information data sheets on the emission control equipment, or plant manufacturing facilities, as required by the Ministry for assessment purposes.

Les feuilles de renseignements sur l'équipement de contrôle des émissions ou les installations de fabrication à l'usine que demande le ministère aux fins d'évaluation.

Note: Similar information for existing processes, plants, etc. located on the same property may be required if they have not previously been submitted to the Ministry. The application will be evaluated based on all existing and proposed contaminant emission sources.

Remarque Le ministère peut également demander des informations semblables sur les procédés, installations, etc., situés sur la même propriété, si elles ne lui ont pas été précédemment fournies. Il évaluera la demande en fonction de toutes les sources existantes et proposées d'émission des polluants.

9. Receptors on Owner's Property
Récepteurs sur la propriété du propriétaire

Distance from Emission Point to Nearest Critical Receptor (air intake, openable window, door, etc.) *Distance entre le point d'émission et le récepteur important le plus proche (prise d'air, fenêtre pouvant s'ouvrir, porte, etc.)*	Metres *mètres*

10. Surrounding Land Use Defined as Immediate Neighbourhood
Utilisation des terres avoisinantes définies comme faisant partie du voisinage immédiat

Distance from Stack to Nearest Building *Distance de la cheminée au bâtiment le plus proche*	Metres *mètres*	Height of this Building *Hauteur de ce bâtiment*	Metres *mètres*
Distance from Stack to Nearest Building Higher than Stack *Distance de la cheminée au bâtiment plus haut que la cheminée le plus proche*	Metres *mètres*	Height of this Building *Hauteur de ce bâtiment*	Metres *mètres*
Adjacent Land Use Designation *Quelle est la désignation de l'utilisation des terres adjacentes?* ☐ Commercial / *Commerciale* ☐ Residential / *Résidentielle* ☐ Industrial / *Industrielle* ☐ Agricultural / *Agricole*		Amendment to an Official Plan or Zoning By-Law Required? *Faudra-t-il apporter une modification au règlement de zonage ou au plan officiel?* ☐ Yes / *Oui* ☐ No / *Non*	

11. General Data About Each Stack, Vent or Exhauster
Renseignements généraux à fournir sur chaque cheminée, évent ou ventilateur d'évacuation

Height Above Roof *Hauteur au-dessus du toit* Metres *mètres*	Above Grade *Par rapport au sol* Metres *mètres*	Stack Exit Diameter *Diamètre de sortie* Metres *mètres*	Construction Material *Matériaux de construction*

Volume of Exhaust Gases *Volume des gaz d'échappement*	Nm³/s Nm³/s	Exit Temperature of Exhaust Gases *Température de sortie des gaz d'échappement*	°C. °C.

Contaminants in Exhaust
Polluants évacués

If Particulate Involved, Particle Size Distribution
S'il y a des particules, distribution de la grosseur des particules

Rate of Contaminant Discharge *Débit d'évacuation des polluants*	g/s g/s	Additional Information Enclosed? *Renseignements complémentaires ci-joints?* ☐ Yes / *Oui* ☐ No / *Non*

12. Toxic or Hazardous Materials
Matériaux toxiques ou dangereux

List chemicals or any other materials used, produced, stored or otherwise present on plant property which could, by any means discharge toxic contaminants or potentially hazardous materials directly or indirectly into the atmosphere.

Énumérer les produits chimiques ou autres matériaux utilisés, produits, entreposés ou autrement présents sur les lieux qui pourraient, d'une façon ou d'une autre, contribuer à l'émission directe ou indirecte dans l'atmosphère de polluants toxiques ou de matériaux pouvant présenter un danger.

Name of Toxic Chemical *Nom du produit chimique toxique*	Use in Plant *Utilisation dans l'usine*	Amount Lost to Atmosphere *Quantité dispersée dans l'atmosphère*

Additional Information Enclosed?
Renseignements complémentaires ci-joints?   ☐ Yes / *Oui*   ☐ No / *Non*

13. Stock Piles
Dépôts de matériaux

Identify stock piles of raw materials, products, or any other material stored in the open that could give rise to emissions. Indicate, if applicable, methods of controlling dust emissions, such as spraying, etc.

Indiquer les dépôts de matières premières, de produits ou d'autres matériaux entreposés en plein air pouvant entraîner des émissions, et, s'il y a lieu, les méthodes prévues pour lutter contre les émissions de poussière, par ex. la pulvérisation, etc.

Additional Information Enclosed?
Renseignements complémentaires ci-joints?   ☐ Yes / *Oui*   ☐ No / *Non*

14. Noise
Bruit

What noise control measures will be undertaken as a result of the operation of the proposed manufacturing plant or emission control facility to maintain noise emission to the natural environment at satisfactory levels?

Mesures prévues pour maintenir le bruit à un niveau acceptable lors de l'exploitation de l'usine ou l'utilisation des installations de contrôle des émissions.

Additional Information Enclosed?
Renseignements complémentaires ci-joints?   ☐ Yes / *Oui*   ☐ No / *Non*   ☐ Not Applicable / *Sans objet*

15. Other Wastes
Autres déchets

Will this installation result in the production of liquid or solid wastes?
Cette installation entraînera-t-elle la production de déchets liquides ou solides?   ☐ Yes / *Oui*   ☐ No / *Non*

If yes, describe nature, quantity, and how they will be handled.
Si oui, décrire la nature et la quantité de ces déchets et leur mode d'élimination.

Additional Information Enclosed?
Renseignements complémentaires ci-joints?   ☐ Yes / *Oui*   ☐ No / *Non*

16. Estimated Capital Costs
Estimation du coût en capital

Cost of Manuf. Plant Process
Coût du procédé $

Labour
Main-d'oeuvre $

Other
Autre $

Total
Total $

Cost of Control Equipment
Coût de l'équipement de contrôle $

Labour
Main-d'oeuvre $

Other
Autre $

Total
Total $

Estimated Annual Operating Cost of Control Equipment
Coût d'exploitation annuel estimatif de l'équipement de contrôle $

17. Schedule
Calendrier

Proposed Starting Date for Construction
Date prévue de début des travaux

Completion Date
Date de fin des travaux

Declaration
Attestation

I hereby declare that the plans, specifications and information provided in this application are true and complete in every respect.
J'atteste par la présente que les plans, cahier des charges et renseignements fournis dans cette demande sont en tous points exacts et véridiques.

Applicant's Signature
Signature du demandeur

Date
Date

Note: If signed by an agent, written authorization duly executed by the proper officers of the owner must be attached.
Remarque: Si la formule est signée par un agent, prière de joindre à la demande un mandat écrit dûment signé par les dirigeants de l'entreprise propriétaire.

Checklist (To be used by applicant in assembling completed application.)
Liste de contrôle à utiliser par le demandeur pour constituer sa demande.

☐ Process-flow diagrams and floor plans including material and heat balances where applicable.
Diagrammes de circulation des matériaux et plans d'étage y compris bilan matières et bilan thermique, le cas échéant.

☐ Plot, roof and elevation plans showing property lines, any emission points, and critical receptors related to on-property structures.
Levé de terrain, plan de structure du toit et élévation indiquant les limites de la propriété et les points d'émission et les récepteurs importants placés sur les structures de la propriété.

☐ Plans showing the relation of the points of emission to off-property structures in the immediate neighbourhood
Plans montrant la situation des points d'émission par rapport aux structures situées en dehors de la propriété dans le voisinage immédiat.

☐ Drawings, design data and Ministry information sheets (if applicable) related to proposed emission control equipment.
Dessins, notice technique du fabricant et feuilles de renseignements à l'intention du ministère (le cas échéant) sur l'équipement proposé de contrôle des émissions.

☐ Application duly signed.
Demande dûment signée.

All information should be supplied in duplicate:
Tous les renseignements doivent être fournis en double exemplaire:

Mail one copy to the Ministry's local district office.

Un exemplaire doit être envoyé par la poste au bureau de district local du ministère.

Mail the second copy to:

Le deuxième exemplaire doit être envoye par la poste à la:

Ministry of the Environment
Environmental Approvals &
Project Engineering Branch
135 St. Clair Avenue West
Toronto, Ontario   M4V 1P4

*Direction des approbations environnementales et des services d'ingénierie
Ministère de l'Environnement
135 ouest, avenue St Clair
Toronto (Ontario)   M4V 1P5*

APPLICATION FOR A CERTIFICATE OF APPROVAL
FOR A WASTE DISPOSAL SITE (PROCESSING)

IMPORTANT NOTE:

If this application is for notification of changes in <u>use</u>, operations, or <u>ownership</u>, specify the MOE number on your certificate _____ and fill in only the data on this form which are being revised.

1. Applicant:

   Municipal ( )   Provincial ( )   Other ( )

   Name:_____

   Address:_____ Postal Code:_____

   City/Prov.:_____ Telephone:_____

   If Applicant not Municipal or Provincial complete the following:

   ( )   Proprietorship
         Name, if different than applicant: ( )   Corporation: President's Name:

   _____   _____

   ( )   Partnership - Name all partners:
         (i) _____   (ii) _____

2. Land Owner:

   Name: _____

   Address: _____

3. Lessee: (if applicable)

   Name: _____

   Address: _____

4. Site Operator

   Name:_____ Title:_____

   Address:_____

5. Site Location:

City	( )	Concession: _____
Town	( ) Name:_____	Lot No: _____
Village	( )	Part of Lot: _____
Township	( )	Street Address: _____
Other _____		_____

Include a copy of the plan of survey of any lands on which the site is to be located.

6. Site Characteristics and Waste Category

    a.   Present land use_____

    b.   Present official plan designation of site _____

    c.   Present zoning category _____

    d.   Present land use of all adjoining properties to be provided on location map.

    e.   Rate at which site can receive waste per day.

                       ( ) Tonnes   ( ) Tonnes
          Domestic_____ ( ) Cu. Meters   Commercial_____ ( ) Cu. Meters

          Processed Organic Waste _____ ( ) Litres

          If any of the following waste categories are intended to be received at the site,
          attached a description of each, including their source to the Application.

                       ( ) Tonnes   ( ) Tonnes
          Liquid Industrial_____ ( ) Cu. Metres Non Hazardous Solid Industrial_____ ( )Cu. Metres
                       ( ) Litres   ( ) Litres

                       ( ) Tonnes   ( ) Tonnes
          Hazardous_____ ( ) Cu. Meters   Other_____ ( ) Cu. Meters
                       ( ) Litres   ( ) Litres

    f.   Number of days/year the site is open_____

    g.   Population served_____

    h.   Names of all municipalities/major industries intended to be served by the site:

          1) _____   4) _____

          2) _____   5) _____

          3) _____

    i.   Total area of site _____hectares or _____ acres

                               ( ) Tonnes
    j.   Estimated storage capacity: _____ ( ) Cu. Meters
          (if intended for storage)   ( ) Litres
          (Rate per day and estimated capacity must be in the same measurement)

    k.   Type of facility:

          ( ) incineration
          ( ) composting
          ( ) resource recovery
          ( ) stabilization/encapsulation
          ( ) packing/baling
          ( ) separation
          ( ) storage
          ( ) grinding/shredding
          ( ) other (specify):_____

7. List all disposal site (for final disposal)

    (i)   Site Certificate No.: _____

            Location: _____

    (ii)   Site Certificate No.: _____

            Location: _____

8. List all supporting documents submitted with this application:

    _____

    _____

    _____

    _____

9. **Signature**

    Applicant Name (printed)   _____

           Title   _____

           (Signature)   _____

           Date   _____

SEAL OF COMPANY
(if applicable)

Ministry
of the
Environment
Ontario

APPLICATION FOR THE APPROVAL OF PLANS AND SPECIFICATIONS FOR THE
CONSTRUCTION OF WORKS FOR THE COLLECTION, TRANSMISSION,
TREATMENT AND DISPOSAL OF INDUSTRIAL WASTEWATER

SECTION 24, THE ONTARIO WATER RESOURCES ACT

NOTE:

(1)   An application for approval shall contain the completed, attached questionnaire and appendices, and all plans, reports, etc., to satisfy items A to D below where applicable and shall be submitted in duplicate.

(2)   Information on the Ministry's industrial pollution control policy, program and procedures is provided in the Information Brief, Environmental Approvals Branch and should be read prior to completing this form.

(3)   New mines and ore milling companies are also required to complete the Ministry's Mineral Industries – Information Sheet Parts I - V.

(4)   Companies establishing manufacturing or production facilities that may produce wastewater having potentially harmful waste characteristics are required to complete Biological and/or Receiving Water Quality Information Sheets together with such other information as the Ministry may require.

A.   Manufacturing Plant Process Description, Water Supply and Waste Disposal

A flow diagram and a written description of the industrial manufacturing process in sufficient detail shall be submitted to indicate:
- Quantity and quality of service water used in a specific process or industrial operation (Item 6, see questionnaire)
- Quantity and measured or estimated quality of liquid waste streams arising from water or other liquid use (Items 7 and 11). In this regard, data such as bioassay results and/or data related to potential toxicity, taste and odour problems or fish tainting shall be submitted where applicable on any characteristic or component of the waste that may adversely affect the environment of the receiving watercourse.

Where the quantity and/or quality of the waste varies according to industrial operating procedure or production rate, the variation in rates of waste flow (average, maximum and minimum) and the maximum and average concentrations of the significant waste components shall be given.

B.   Report on Design of Proposed Waste Treatment Works

Engineering reports on the proposed treatment works should be submitted and shall indicate:
- Expected flow and concentrations of liquid industrial wastes, and means of measuring, from all processes contributing to the treatment plant influent (Items 7 and 11).
- A flow diagram relating the proposed treatment processes.
- Function, capacity and operation of the individual components comprising the treatment facilities, and the system as a whole. Performance data should be given where possible.
- Quantities of treatment chemicals.
- Expected degree of reduction in pollutional load to be effected by the system. Supporting research or pilot plant data shall be given where possible.
- A statement setting forth the expected bacterial, physical, chemical and other known characteristics of the treated effluent (Item 13).
- Method of sludge disposal, and disposal of other solid or liquid process wastes.

C. Physical Lay-Out

    1. A general arrangement or lay-out sketch of the property shall be submitted (to scale or approximate) to co-ordinate buildings, treatment or disposal works, property boundaries, municipal boundaries, effluent lines, points of discharge of outfalls in relation to the receiving water, and municipal sanitary sewer connections.

    2. Also, drawings or sketches of plant areas in sufficient detail to indicate:
- Size and location of industrial process equipment concerned.
- Location and sizes of collection and transmission sewers including sewers transporting uncontaminated waters entering the treatment or effluent system. Existing sewers shall be differentiated from proposed sewers and direction of flow in sewers shall be shown.
- Location of all equipment involved in the proposed treatment, control or disposal of wastes. Existing equipment shall be differentiated from proposed equipment.

D. Plans of Treatment Works

    1. Engineering drawings shall include plans and profiles of each unit in the treatment or control system.

    2. Plans and profiles of outfall sewers at the receiving water should also be submitted.

Under the Act, the undersigned, as owner ☐ or agent ☐ , applies for approval of plans and specifications, submitted herewith for the construction of

new industrial waste treatment or control works .... ☐

a modification or addition to existing industrial waste works .... ☐

consisting of: (brief description of proposal as related to this application)

. . . .

. . . .

. . . .

. . . .

. . . .

and submits the following information:

1. Name of Applicant. . . . .
                     (Company, corporation, owner)   (telephone number)

      . . . .
                     (postal address)   (county)

2. Location of Industry . . . .
                           (number, street, road or lot number, municipality, county)

    NOTE: For plants producing various products or having a number of waste producing operations, items 3 to 23 which follow, should cover only details concerned with the specific proposal under consideration, including all inter-related process and treatment systems.

3. Production Data (List principal materials used and products produced, giving volume, weight, or quantity per day, week or other production period.)

      Raw Materials . . . .

      . . . .

      Products   . . . .

      . . . .

      Current Production Level . . . .

      Future Production level and date . . . .

4. Industrial Operating Schedule –

hours per day ....

days per week ....

weeks per year..

indicate shift periods..

5. Number of Employees:

Office (Admin., Management) ....

Production ....

6. Water Supply:

	Source of Water	Litres Per Day		
		Average	Maximum	Minimum
(a)	Industrial Processes	....	....	....
	....	....	....	....
	....	....	....	....
(b)	Cooling, Condensers, Compressors	....	....	....
(c)	Drinking and Sanitary	....	....	....
(d)	Other	....	....	....
	TOTAL SUPPLY	....	....	....

If daily supply varies from above total, explain in appendix.. ☐

NOTE: If water in excess of 50,000 litres per day is to be taken from other than a municipal water supply, approval
is required from the Ministry's Water Resources Branch, Toronto. (Section 20, Ontario Water Resources Act).

7. Waste Disposal:

	Origin of Wastes or Description	Litres Per Day		
		Average	Maximum	Minimum
(a)	Process Waste Streams (itemize)	....	....	....
	....	....	....	....
	....	....	....	....
	....	....	....	....
	....	....	....	....
(b)	Batch Discharges	....	....	....
	....	....	....	....
	....	....	....	....
(c)	Cooling and Condenser Water	....	....	....
(d)	Sanitary Sewage	....	....	....
(e)	Other	....	....	....
	TOTAL	....	....	....

If combined daily waste flow for disposal varies from above total, explain in appendix .... ☐

8.   Proposed route to, and ultimate point of waste discharge (municipal sewer, surface drain, lake, river, pond, leaching pit, etc. Give name of surface drain, lake or river. If discharge is to a tributary, also give name of main watercourse).

    (a)   Process Wastes   ....
          (itemize)
                                    ....

    (b)   Batch Discharges ....

                                    ....

    (c)   Cooling and Condenser Water ....

    (d)   Sanitary Sewage ....

    (e)   Other   ....

9.   Where a new connection or an increased effluent discharge to a municipal sewer is proposed, municipal authorization is required. Has this authorization been obtained?

                            Yes ☐   No ☐

10.   List all chemicals used, produced, stored, or otherwise present on plant property which could, by any means, drain, gain access or be discharged directly or indirectly in any effluent or waste flow leaving the plant or plant property.

Name of Chemical	Use of Chemical in Plant	Amount Lost to Effluent or Watercourse
....	....	....
....	....	....
....	....	....
....	....	....

             See appendix for discussion ....   ☐

11.   Thermal Characteristics

    (a)   Water Supplies

          What are the expected temperatures in °C of the industrial process and cooling water supplies outlined in Section 6?

	(May – October)		(November – April)	
Process:	Avg........°C	Max.......°C	Avg........°C	Max.......°C
Cooling:	Avg........°C	Max.......°C	Avg........°C	Max.......°C

    (b)   Waste Streams

          What are the expected temperatures in °C of the treated effluents or process wastewater and spent cooling water streams outlined in Section 7?

Process or treated effluents (itemize)	(May – October)		(November – April)	
	Avg........°C	Max........°C	Avg........°C	Max.......°C
	......	....	....	....
....	......	....	......	....
....	......	....	....	....
....	......	....	....	....
....	......	....	....	....
....	......	....	....	....
Cooling water	......	....	....	....

(c)　　If the waste streams listed in (b) are to be combined with existing waste discharges, what are the expected temperatures and volumetric flow rates of each combined discharge?

Combined discharge description	(May – October)		(November – April)		Combine flow – Litres per day	
	Avg........°C	Max........°C	Avg........°C	Max........°C	Avg.	Max.
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....

12. Expected Characteristics of Waste Effluents before treatment

....
....
....

　　　　See appendix for analytical detail .... ☐

13. Expected Characteristics of treated waste flows and final effluent

....
....
....

　　　　See appendix for analytical detail .... ☐

14. Proposed method of treated effluent flow measurement

　　continuous flow recording device.. ☐

　　non-recording device... ☐

　　other .... ☐

　　see appendix .... ☐

15. Proposed Effluent Quality Monitoring Program (See Information Brief)

　　(a)　automatic continuous sampling... ☐

　　　　periodic composite sampling .... ☐

　　　　periodic grab samples .... ☐

　　　　Sampling frequency　once per shift ☐　daily ☐　weekly ☐　monthly ☐　batch ☐

　　(b)　Samples to be analyzed for

　　　　　BOD₅ ☐　　　　　　Suspended Solids ☐　　　　　pH ☐

　　　　　Others.......... ☐ .... ☐ .... ☐ .... ☐

　　　　　See appendix for detail .... ☐

16. If a leaching pit, oxidation pond, or spray or land irrigation system is proposed, the distance to the nearest:

    (a) Surface watercourse is .... Metres

    (b) Private well is .... Metres

    (c) Municipal well is .... Metres

    (d) Dwelling or built-up area is.. .... Metres

17. Power failures — indicate the number and duration of power failures during the past five years

    number and dates...

    duration of each ....

    see appendix .... ☐

18. Describe facilities that will be available or precautions that will be taken to prevent the discharge of untreated wastes or the discharge of any material that could impair the quality of the receiving water in the event of power failures, treatment plant mechanical failures or manufacturing plant equipment failures involving spills or leaks. (Items such as standby pumps, emergency holding tanks, spill ponds, etc., are to be included here.)

    ....

    ....

    ....

    ....

    ....

    See appendix .... ☐

19. Are any solid wastes, other than those which can be picked up by the local garbage collection agency, generated in the process:

    Yes ☐   No ☐

    If yes, describe nature and quantity ....
    ....
    ....

20. Proposed starting date for construction of proposed industrial waste treatment or control works ....

    Proposed completion date of works ....

21. Estimate of capital cost of proposed industrial waste treatment or control works ....

        Breakdown of capital cost estimate

            Equipment   ....

            Labour   ....

            Land   ....

            Other   ....

            Total   ....

                See appendix .... ☐

            Engineering Charges ....

            Estimate of annual costs of operation ....

22. Describe the manner in which the proposed facilities are to be operated. (Operating procedures should include schedule of operation, manpower requirements, maintenance schedule, etc. Operator qualifications should also be indicated.)

. . . . Appendix . . . . ☐

23. Study of performance or operating efficiency of installed treatment system. State:

How and when will the performance evaluation program be carried out . . . .

. . . . Appendix. . . ☐

Who will make the evaluation . . . . Appendix . . . ☐

Submitted in accordance with Section 24 and with the knowledge of Section 59, Ontario Water Resources Act.

Date . . . .
                                                                                    (Printed Name of Officer of Owner)

. . . .
                                                            (Signature)

. . . .
                                                            (Title)

NOTE: If signed by an agent, written authorization duly executed by the proper officers of the owner must accompany this application.

CHECK LIST TO BE USED BY APPLICANT
IN ASSEMBLING COMPLETED APPLICATION
CONSISTING OF REPORTS, PLANS, DIAGRAMS, ETC.

(1) Engineering report on treatment works – including the required information (item B) and appropriate appendices of the questionnaire . . . . ☐

(2) Flow diagram of manufacturing processes indicating origin of waste flows (item A) . . . . ☐

(3) Flow diagram of proposed waste treatment or control works (item B) . . . . ☐

(4) General arrangement drawing or sketch of plant property to coordinate buildings, treatment works, outfalls, etc. . . . . ☐

(5) Sewer layout drawing (items 4 and 5 may be combined on one drawing, if convenient). . . . . ☐

(6) Engineering drawings showing plans and profiles of each unit in the treatment or control system . . . . ☐

(7) Mineral Industries Information Sheet, if applicable . . . . ☐

(8) Application duly signed . . . . ☐

.

....

(Name of Company or Other Owner)

Application to

MINISTRY OF THE ENVIRONMENT
ONTARIO

for Constructing

INDUSTRIAL WASTE TREATMENT WORKS

INDUSTRIAL WASTE SEWERS

MISCELLANEOUS STRUCTURES

TO THE DIRECTOR, ENVIRONMENTAL APPROVALS BRANCH

The work herein described in this application by ....

.... of ....

is recommended for approval with the issue of certificate for ....

....with the proviso

that ....

....

Date ....

Reviewed by.. Manager
Industrial Approvals Section

APPENDIX C.1

THERMODYNAMICS REFRESHER

.

A set of graphs and tables have been developed to allow
relatively quick and reasonable calculation of incinerator
parameters. The use of these materials requires familiarity
with basic thermodynamic principles, which will be discussed
in this appendix.

C.1.1 Equilibrium Equation

Chemical equilibrium equations are developed to indicate
conservation of matter, i.e., the molecular weight on the
left side of the equation equals the molecular weight on the
right. For carbon:

$$C + O_2 \rightarrow CO_2$$
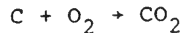
The atomic weight of carbon is 12.01, and of oxygen, 16.00.
For this simple example, therefore, the atomic weight on the
left-hand side is $(1 \times 12.01) + (2 \times 16.00) = 44.01$, which
is equal to the weight of CO_2 on the right-hand side of the
equation.

In the wastes and fuels normally encountered, the major
constituents include carbon and hydrogen. For hydrogen:

$$2H_2 + O_2 \rightarrow 2H_2O$$
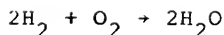
Note that oxygen or hydrogen exist as diatomic molecules (O_2 and H_2), as does nitrogen (N_2).

The equilibrium equation for methane, CH_4, is:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$
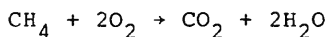
Note that the total molecules of each element on the left are equal to the total molecules of each element in the right (one C, four H, four O).

C.1.2 Basic Combustion Calculations

In most situations waste, or fuel, is combusted with air. Air is composed of nitrogen and oxygen. For a burning reaction to proceed, oxygen must be introduced; nitrogen will also be present along with the oxygen (3.756 molecules N_2 per molecule O_2). For carbon:

$$C + O_2 + 3.76N_2 \rightarrow CO_2 + 3.76N_2$$
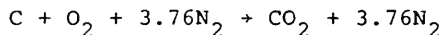
The number of molecules of each substance present (moles) is proportional to the volume of that substance.

The weight of each constituent is proportional to its atomic weight. Inserting the atomic weights into this equation:

$$12.01 \quad 32.00 \quad 28.02 \quad 44.01 \quad 28.02$$

$$C \;+\; O_2 \;+\; 3.76N_2 \;\rightarrow\; CO_2 \;+\; 3.76N_2$$
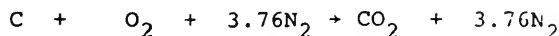
$$12.01 \quad 32.00 \quad 106.36 \quad 44.01 \quad 105.36$$

$$1.00 \quad 2.66 \quad 8.77 \quad 3.66 \quad 8.77$$

The first line beneath this equilibrium equation represents the total weight of each element present as calculated from its molecular weight above the equation. The second line relates each element to one kilogram of carbon and is obtained by dividing the constituent weights by the molecular weight of carbon, 12.01.

Note first that the sum of the constituent weights on one side, $12.01 + 32.00 + 105.36 = 149.37$, equals that on the other side of the equation, $44.01 + 105.36 = 149.37$. Likewise, normalized to one kilogram of carbon, the constituent weights are equal, one side to the other: $1.00 + 2.66 + 6.77 = 12.43$, $3.66 + 8.77 = 12.43$.

By normalizing this reaction to one kilogram of carbon, the determination that follows is apparent.

For burning one kilogram of carbon, 2.66 kilograms of O_2 are required, 2.66 + 8.77 = 11.43 kilograms of air are required, 3.66 kilograms of CO_2 are generated, and 3.66 + 8.77 = 12.43 kilograms of combustion products are produced.

Applying similar calculations to the combustion of hydrogen gives:

$$2.02 \quad 32.00 \quad 28.02 \qquad 18.02 \quad 28.02$$

$$2H_2 \; + \quad O_2 \; + \; 3.76N_2 \quad \rightarrow \quad 2H_2O \; + \; 3.76N_2$$
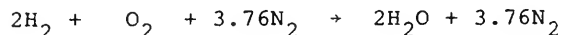
$$4.04 \quad 32.00 \quad 105.26 \qquad 35.04 \quad 105.36$$

$$1.00 \quad 7.92 \quad 26.08 \qquad 8.92 \quad 26.08$$

Therefore, for burning one kilogram of hydrogen, 7.92 kilo-grams of O_2 are required, 7.92 + 26.08 = 34.00 kilograms of air are required, 8.92 kilograms of H_2O are generated, and 8.92 + 26.08 = 35.00 kilograms of combustion products are produced.

C.1.3   Stoichiometric Burning

The examples of combustion illustrated above utilized only that amount of air required for complete combustion to CO_2 or to H_2O. All the oxygen provided was used up in the

generation of CO_2 and H_2O and no free oxygen was left in the products of combustion. This condition is known as complete combustion (provision of 100 percent of total air, zero excess air) and defines the stoichiometric condition. When stoichiometric air or stoichiometric oxygen is referred to, it defines the condition where only that amount of air, or oxygen, is provided to ensure complete combustion in accordance with the chemical equilibrium equation. For carbon, the stoichiometric air requirement is 11.43 kilograms per kilogram of carbon, and for hydrogen, 34.00 kilograms of stoichiometric air per kilogram of hydrogen, as previously calculated.

C.1.4 Excess Air

Combustion calculations must relate to actual burning equipment requirements if they are to have any validity. In practice, the air provided for complete burning must be greater than the stoichiometric requirement. The stoichiometric air value implies a burning process with 100 percent efficiency, where air is in contact with 100 percent of the waste (or fuel) surface, no air is wasted, and the burning reaction occurs instantaneously. In actuality, in order to achieve complete burning, an amount of air greater than the stoichiometric requirement must be provided.

For burning gaseous fuels, a total air requirement of 5 percent above stoichiometric may be sufficient, but for burning solid wastes or sludges in a multiple chamber furnace, excess air of 100 to 200 percent of stoichiometric may be required.

C.1.5 Excess Air Calculations

Burning a simple fuel, benzene (C_6H_6), at stoichiometric conditions:

| 78.12 | 32.00 | 28.02 | 44.01 | 18.02 | 28.02 |

$$C_6H_6 \; + \; 7.5O_2 \; + \; (7.5 \times 3.76)N_2 \; \rightarrow \; 6CO_2 \; + \; 3H_2O \; + \; 1.5O_2 \; + \; 33.64N_2$$

| 78.12 | 240.00 | 790.16 | 264.06 | 54.06 | 790.16 |
| 1.00 | 3.07 | 10.11 | 3.38 | 0.69 | 10.11 |
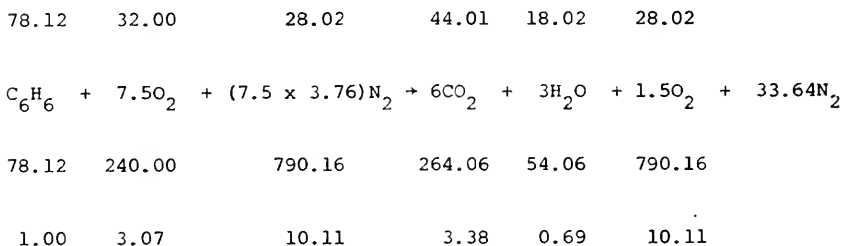
The stoichiometric oxygen is 3.07 lb per lb C_6H_6, 7.5 moles O_2 per mole of C_6H_6. For 20% excess air an additional amount of oxygen, 20% of 7.5 or 1.5 moles of oxygen must be added to this reaction. With 7.5 moles of oxygen required for combustion of fuel, therefore, the additional 1.5 moles of oxygen added in the air will appear in the flue gas, as follows:

78.12	32.00	28.02		44.01	18.02	32.00	28.02

$$C_6H_6 + (7.5 + 1.5)O_2 + (9 \times 3.76)N_2 \rightarrow 6CO_2 + 3H_2O + 1.5O_2 + 33.64N_2$$

78.12	288.00	948.20		264.06	54.06	48.00	948.20
1.00	3.69	12.14		3.38	0.69	0.62	12.14

When burning a waste or fuel containing oxygen, such as cellulose ($C_6H_{10}O_5$), the main constituent of paper, calculations of excess air must consider the oxygen component of the fuel.

For stoichiometric conditions:

162.16	32.00	28.02		44.01	18.02	28.02

$$C_6H_{10}O_5 + 6O_2 + (6 \times 3.76)N_2 \rightarrow 6CO_2 + 5H_2O + 22.56N_2$$

162.16	192.00	632.13		264.06	90.10	632.13
1.00	1.19	3.90		1.63	0.56	3.90

When calculating excess air requirements for burning, consider that 6 moles of O_2 define the stoichiometric requirements.

Therefore, for 150 percent excess air, an additional 6 x 1.5 = 9.0 moles of O_2 must be introduced, as follows:

162.16	32.00	28.02	44.01	18.02	32.00	28.02

$$C_2H_{10}O_5 \;+\; (6 + 9)O_2 \;+\; (15 \times 3.76)N_2 \;\rightarrow\; 6CO_2 \;+\; 5H_2O \;+\; 9O_2 \;+\; 56.40N_2$$

162.16	480.00	1580.33	264.06	90.10	288.00	1580.33
1.00	2.69	9.75	1.63	0.56	1.77	9.75

C.1.6 Enthalpy

To facilitate quantification of these laws, a number of
material properties have been defined. Of interest to an
understanding of combustion and related processes, the total
energy, or enthalpy, is of particular concern. Enthalpy, h
(kJ/kg) is the total energy of a substance at one tempera-
ture relative to the energy of the same substance at another
temperature. It is a relative property, and whenever it is
used, it must be related to a base or datum point.

Figures C.1-1 and C.1-2 present enthalpy of water vapor and
air as a function of temperature. The enthalpies are
related to a base of zero degrees Celsius.

C.1.7 System Boundary

A system boundary (SB) is a definition of the entire process
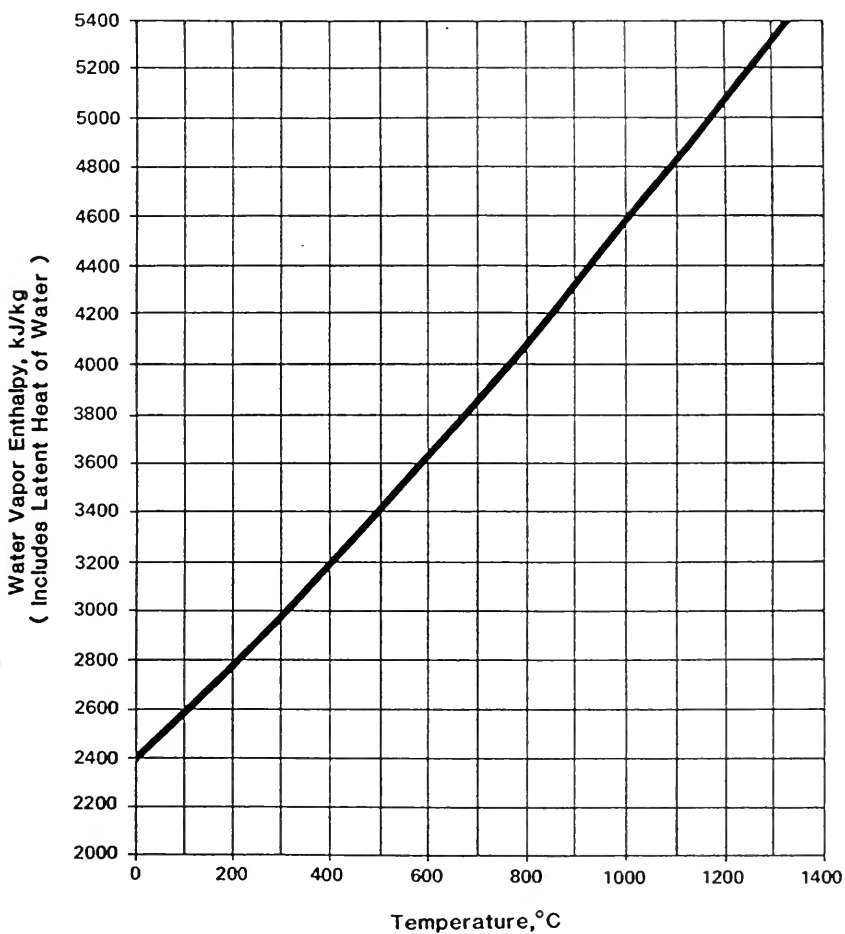
Figure C.1-1

ENTHALPY, WATER VAPOR RELATIVE TO 0°C
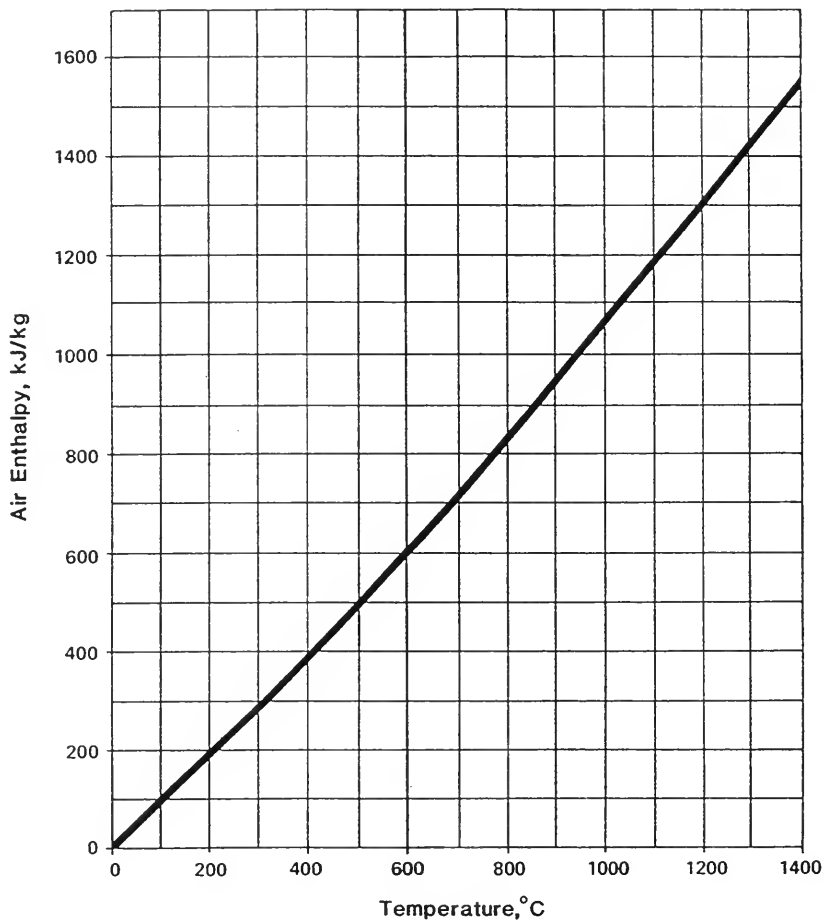
**Figure C.1-2
ENTHALPY, DRY AIR RELATIVE TO 0°C**

under observation. It provides a means to facilitate rela-
tionships, or calculations, relative to this process. For
instance, in Figure C.1-3, the multiple hearth furnace is
under observation. From the first law of thermodynamics,
mass flow and heat flow across an SB must each total zero.
Therefore:

Mass Flow: $M_a + M_f - M_g - M_r = 0$

Heat Flow: $Q_f + M_a h_a = M_g h_g - M_r h_r = 0$

Where Q_f is the heat of combustion of the feed (sludge) in
kJ/hr, M is the mass flow in kg/hr, and h is enthalpy in
kJ/kg.

C.1.8   Reaction Temperature

The temperature of a reaction can be calculated knowing the
heat produced by the reaction and the quantities of products
generated in the reaction. For example, if 200 kilograms of
water vapor and 3000 kilograms of dry gas are produced in a
reaction generating 450 000 kJ, what is the reaction tem-
perature? This temperature is that value at which the en-
thalpy of the products of combustion equal the heat input to
the system. A determination of reaction temperature is
based on trial and error.
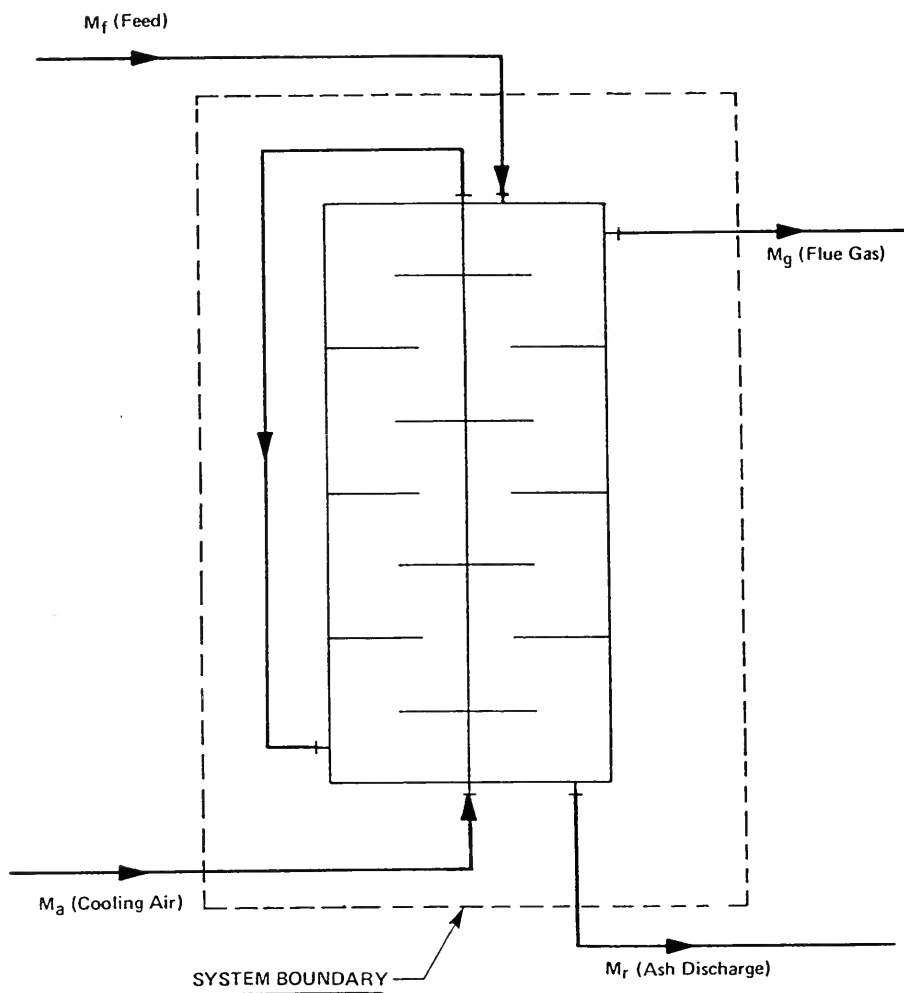
Figure C.1-3
MULTIPLE HEARTH INCINERATOR

Assume the reaction temperature in this case is 1000°C.
From Figure C.1-1, at 1000°C the enthalpy of moisture is
4300 kJ/kg and from Figure C.1-2 that of air (dry gas) is
1000 kJ/kg.

Net Enthalpy: Dry gas   1000 kJ/kg x 300 kg = 400 000 kJ

               Moisture   4300 kJ/kg x 20 kg = 86 000 kJ

               TOTAL   486 000 kJ

This total is greater than the heat generated in the
reaction, 450000 kJ. A second run will be made, assuming
900°C reaction temperature:

Net Enthalpy: Dry gas   950 kJ/kg x 300 kg = 286 000 kJ

               Moisture   41 560 kJ/kg x 20 kg = 83 000 kJ

               TOTAL   368 000 kJ

The actual temperature of the reaction is between these two
assumed values and can be interpolated as follows:

Reaction temperature:

$$= 900 + \frac{(450\ 000 - 368\ 000)}{(486\ 000 - 368\ 000)} \times (1000 - 900)$$

$$= 969°C$$

This example did not consider losses because of radiation from the furnace or ash discharge losses. To include these losses in this calculation, they would be subtracted from the available (generated) heat. The net result would be a decrease in reaction temperature.

APPENDIX C.2

TECHNICAL DATA

AIR COMPOSITION

	By Weight	By Volume
Oxygen in air	0.2315	0.21
Nitrogen in air	0.7685	0.79
Air to oxygen	4.3197	4.7619
Oxygen to nitrogen	0.3012	0.2658
Molecular weight, average	28.9414	

CHEMICAL ELEMENTS

Element	Symbol	Atomic No.	Atomic Weight
Actinium	Ac	89	227.
Aluminum	Al	13	26.98
Americuium	Am	95	243.
Antimony	Sb	51	121.75
Argon	Ar	18	39.95
Arsenic	As	33	74.92
Astatine	At	85	210.
Barium	Ba	56	137.34
Berkelium	Bk	97	247.
Beryllium	Be	4	9.01
Bismuth	Bi	83	208.98
Boron	B	5	10.81
Bromine	Br	35	79.90
Cadmium	Cd	48	112.40
Calcium	Ca	20	40.08
Californium	Cf	98	251.
Carbon	C	6	12.01
Cerium	Ce	58	140.12
Cesium	Cs	55	132.91
Chlorine	Cl	17	35.45
Chromium	Cr	24	52.00
Cobalt	Co	27	58.93
Columbium (see Niobium)			
Copper	Cu	29	63.55
Curium	Cm	96	247.
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	254.
Erbium	Er	68	167.26
Europium	Eu	63	151.96
Fermium	Fm	100	253.
Fluorine	F	9	19.00
Francium	Fr	87	223.
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.72
Germanium	Ge	32	72.59
Gold	Au	79	196.97
Hafnium	Hf	72	178.49
Helium	He	2	4.00
Holmium	Ho	67	164.93
Hydrogen	H	1	1.01
Indium	In	49	114.82
Iodine	I	53	126.90
Iridium	Ir	77	192.2

Unit	Multiplied By	Equals
Atmosphere	101,325	Pascals
Atmospheres	14.696	Pounds per square inch
Barrels (oil)	0.15899	Cubic meters
Boiler Horsepower	9.803	Kilowatts
Btu	1055.1	Joules
Btu per cubic foot	37.260	Joules per cubic meter
Btu per hour	0.29307	Watts
Btu per pound	2326	Joules per kilogram
Btu per pound per degree Fahrenheit	4187	Joules per kilogram per degree Celsius
Btu per square foot per hour	3.1546	Joules per square meter per hour
Cubic feet	0.028317	Cubic meters
Cubic yards	0.76456	Cubic meters
Feet	0.3048	Meters
Feet of water at 39.2°F	2989	Pascals
Foot pounds force	1.3558	Joules
Gallons (US)	0.003785	Cubic meters
Gallons (US)	1.201	Gallons (Imperial)
Gallons (Imperial)	0.004545	Cubic meters
Horsepower (British)	745.7	Watts
Inches of water at 60°F	248.84	Pascals
Joules	2.7778×10^{-7}	Kilowatt-hours
Kilograms	2.203	Pounds
Miles	1609.3	Meters
Pounds	0.45359	Kilograms
Pounds per cubic foot	16.018	Kilograms per cubic meter
Pounds per square inch	6894.8	Pascals
Tons	907.18	Kilogram
Watts	1	Joules per second

APPENDIX C.3

DESIGN EXAMPLES

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1. Feed rate	5000 kg/h	in example statement
2. Moisture fraction	.75	in example statement
3. Moisture quantity	5000 x 0.75 = 3750 kg/h	(1x2)
4. Solids quantity	5000 - 3750 = 1250 kg/h	(1-3)
5. Noncumbustible Fraction	0.5	in example statement
6. Noncombustible quantity	0.5 x 1250 = 625 kg/h	(4x5)
7. Combustible quantity	1250-625 = 625 kg/h	(4-6)
8. Heating value	23 000 kJ/kg combustible	in example statement
9. Heat generated	625 x 23,000 = 14.375×10^6 kJ/h	(7x8)
10. Stoichiometric Air Ratio	7 kg air/kg combustible	From Fig. 4-2a
11. Stoichiometric Air	7 x 625 = 4375 kg/h	(7 x 10)
12. Excess Air Fraction	1.00	in example statement
13. Excess Air Required	1 x 4375 = 4375 kg/h	(11x12)
14. Total Air Required	4375 + 4375 = 8750 kg/h	(11+13)
15. Moisture generated	0.52 kg water/kg combustible	from Figure 4-2b
16. Moisture generated	625 x 0.52 = 325 kg/h	(7x15)
17. Humidity in air	.00657 kg water/kg air	from example statement
18. Humidity	0.00657 x 8750 = 57 kg/h	(14x17)
19. Total Moisture	3750 + 325 + 57 = 4132 kg/h	(3+16+18)
20. Dry flue gas	625 + 8750 - 325 = 9050 kg/h	(7+14-16)
21. Radiant heat loss	$0.01 \times 14.375 \times 10^6 =$ 0.14×10^6 kJ/h	1%x(9)
22. Ash heat content	200 kJ/kg	in example statement

23. Ash heat loss $625 \times 200 =$ (6x22)

                                  0.125×10^6 kJ/h

24. Humidity Correction $57 \times 2186 =$ (18)x2186

                                  $.125 \times 10^6$ kJ/h

25. Miscellaneous heat   0   None

   loss

26. Heat in flue gas $14.375 -0.14 -.125 +.125 -0$ (9-21-23+24-25)

                                  $= 14.235 \times 10^6$ kJ/h

27. Flue gas temperature   Calculate from Figures

                                 C.1-1 & C.1-2. Estimate

                                 temperature, check enthalpy

                                 against (26), and re-estimate:

                                 @ 200°C enthalpy of air

                                 and moisture is 190 and

                                 2790 kJ/kg respectively.

                                 With 9050 kg/h dry gas and

                                 4132 kg/h moisture the

                                 total enthalpy of the stream

                                 is 190 x 9050 + 2790 x 4132

                                 $= 13.25 \times 10^6$ kJ/h.

                                 @ 400°C the enthalpy of air

                                 and water vapor is 380 and

                                 3200 kJ/kg respectively, for

                                 a total stream heat content

                                 of 380 x 9050 + 3200 x 4132

                                 $= 16.66 \times 10^6$ kJ/kg.

                                 The heat content of the flue

                                 gas, 14.235×10^6 kJ/h, is

                                 C.3-3

gas, 14.235×10^6 kJ/h, is
equivalent, by interpola-
tion, to:

200 +

(400-200) $\dfrac{[14.235 - 13.25]}{[16.66 - 14.235]}$

= 258°C

28. Required gas temperature	760°C	in example statement
29. Required Enthalpy of flue gas	Calculate from required temperature and Figures C.1-1 and C.1-2: T = 760°C (From Figures C.1-1 and C.1-2) Air Enthalpy = 780 kJ/kg x 9050 kg/h = 7.06 x 10^6 kJ/h Water Enthalpy = 3990 kJ/kg x 4132 kg/h = 16.49 x 10^6 kJ/h Total Enthalpy = 23.55 x 10^6 kJ/h	19, 20, 27
30. Net heat required	(23.55-14.235) x 10^6 = 9.315 x 10^6 kJ/h	29-26
31. Fuel excess air	0.2	in example statement

32. Fuel required	9.315×10^{6} kJ/h ÷ 22 000	Figures 4-4, 4-5,
	kJ/gal = 423 l/h	30, 31
33. Air required for fuel	15.03 kg/l	Table 4-5, 30
34. Air required for fuel	15.03 x 423 = 6379 kg/h	33x32
35. Moisture from fuel	1.05 kg/l	Table 4-5, 30
36. Moisture generated	1.05 x 423 = 444 kg/h	35x32
37. Dry gas from fuel	15.09 kg/l	Table 4-5, 30
38. Dry gas generated	15.09 x 423 = 6383 kg/h	37x32
39. Total dry gas flow	6383 + 9050 = 15 433 kg/h	38+20
40. Total moisture flow	444 + 4132 = 4576 kg/h	36+19
41. Total heat at exit	14.235×10^{6} + 423 x 39 100	26 + 32 x (fuel gross
	$= 30.774 \times 10^{6}$ kJ/h	htg. value)

Table C.3-1

SLUDGE INCINERATOR ANALYSIS

1.	Feed quantity (as received)	5000	Given
2.	Moisture fraction	.75	Given
3.	Moisture quantity (kg/h)	3750	1 x 2
4.	Solids quantity (kg/h)	1250	1 - 3
5.	Noncombustible fraction	0.50	Given
6.	Noncombustible quantity (kg/h)	625	4 x 5
7.	Combustible quantity (kg/h)	625	4 - 6
8.	Heating value (kJ/kg combustible)	23 000	Given
9.	Total heat generated (kJ/h)	14 375 000	7 x 8
10.	Stoichiometric air ratio (kg/kg combustible)	7.0	Figure 4-2
11.	Stoichiometric air (kg/h)	4375	7 x 10
12.	Excess air fraction	1.00	Given
13.	Excess air (kg/h)	4375	11 x 12
14.	Total air required (kg/h)	8750	11 + 13
15.	Moisture generated (kg/kg combustible)	0.52	Figure 4-3
16.	Moisture generated (kg/h)	325	7 x 15
17.	Humidity (kg/kg dry air)	0.00657	Given
18.	Humidity (kg/h)	57	14 x 17
19.	Total moisture (kg/h)	4132	3 + 16 + 18
20.	Dry flue gas (kg/h)	9050	7 + 14 - 16
21.	Radiation heat loss (kJ/h)	140 000	Given
22.	Ash heating value (kJ/kg)	200	Given
23.	Ash heat loss (kJ/h)	125 000	6 x 22
24.	Humidity Correction (KJ/h)	125 000	18 x 2,186
25.	Miscellaneous heat loss (kJ/h)	0	Given
26.	Heat in flue gas (kJ/h)	14 235 000	9 - 21 - 23 + 24 - 25
27.	Flue gas temperature (°C)	258	19, 20, 25
28.	Required gas temperature (°C)	760	Given
29.	Required flue gas heat content (kJ/h)	23 550 000	19, 20, 28
30.	Heat required (kJ/h)	9 315 000	29-26
31.	Fuel excess air	0.2	Given
32.	Fuel required (1 or m³/h)	423	Figures 4-3a, 30, 31
33.	Air for fuel (kg air/1 or m³)	15.03	Table 4-7, 31
34.	Air required (kg/h)	6379	33 x 32
35.	Moisture from fuel (kg/1 or m³)	1.05	Table 4-5, 31
36.	Moisture generated (kg/h)	444	35 x 31
37.	Dry gas from fuel (kg/1 or m³)	15.09	Table 4-5, 31
38.	Dry gas generated (kg/h)	6383	37 x 32
39.	Total dry gas flow (kg/h)	15 433	38 + 20
40.	Total moisture flow (kg/h)	4576	36 + 19
41.	Total heat at exit (kJ/h)	30 774 000	26 + 32 x (fuel gross htg. value)

Example 2: Refuse Incineration

Refuse, 50 tonnes per day (2083 kg/h) is to be incinerated.
It has a moisture content of 24%, a heating value of
11 000 kJ/kg as received and an ash (non-combustible)
content of 11%, as received. The incinerator is of grate
design, requires 85% excess air for complete combustion. A
minimum temperature of 980°C is required for effective burn
out. Assume an ash heat content of 250 kJ/kg, 2% radiation
heat loss, and a humidity of .00657 kg/kg dry air.

Calculations follow and are summarized in Table C.3-2

1. Feed rate	2083 kg/h	in example statement
2. Moisture fraction	.24	in example statement
3. Moisture quantity	2083 x .24 = 500 kg/h	(1x2)
4. Solids quantity	2083 - 500 = 1583 kg/h	(1-3)
5. Noncumbustible Fraction	0.11 ÷ (1-0.24) = 0.145	in example statement
6. Noncombustible quantity	1583 x .145 = 230 kg/h	(4x5)
7. Combustible quantity	1583 - 230 - 1353 kg/h	(4-6)
8. Heating value	11 000 x (2083/1353)	in example statement
	= 16 935 kJ/kg	
9. Heat generated	1353 x 16 935 = 22 913 000 kJ/h	(7x8)
10. Stoichiometric Air Ratio	5.1 kg air/kg combustible	From Fig. 4-2a
11. Stoichiometric Air	1353 x 5.1 = 6900 kg/h	(7 x 10)
12. Excess Air Fraction	.85	in example statement
13. Excess Air Required	6900 x 8.5 = 5865 kJ/h	(11x12)
14. Total Air Required ·	6900 + 5865 = 12 765 kJ/h	(11+13)
15. Moisture generated	.43 kg water/kg combustible	from Figure 4-2b
16. Moisture generated	1353 x .43 = 582 kg/h	(7x15)
17. Humidity in air	.00657 kg water/kg air	from example statement
18. Humidity	12 765 x .00657 = 84 kg/h	(14x17)
19. Total Moisture	500 + 582 + 84 = 1166 kg/h	(3+16+18)
20. Dry flue gas	1353 + 12765 - 582	(7+14-16)
	= 13 536 kg/h	
21. Radiant heat loss	0.02 x 22 913 000 - 458 000 kg/h	2%x(9)
22. Ash heat content	250 kJ/kg	in example statement

23. Ash heat loss   230 x 250 = 5800 kJ/h   (6x22)

24. Humidity Correction   84 x 2186 = 184 000 kJ/h   (18)x2186

25. Miscellaneous heat   0   None

     loss

26. Heat in flue gas   22 913 000 - 458 000 - 58 000   (9-21-23+24-25)

                             + 184 000 - 0

                             = 22 581 000 kJ/h

27. Flue gas temperature   Calculate from Figures

                             C.1-1. & C.1-2. Estimate

                             temperature, check enthalpy

                             against (26), and re-estimate:

                             @ 1000°C enthalpy of air

                             and moisture in 1070 and

                             4590 kJ/kg respectively.

                             With 13 536 kg/h dry gas

                             and 1166 kg/h moisture

                             the total enthalpy of the

                             stream is 1070 x 1356 + 4590

                             x 166 = 19.835×10^6 kJ/h.

                             @ 1200°C the enthalpy of

                             air and moisture is 1300 and

                             5060 kJ/kg respectively, for

                             a total stream heat content

                             of 14000 x 12536 + 1166

                             = 23.497×10^6 kJ/h.

                             The heat content of the flue

                             gas, 22.581×10^6 kJ/h, is

equivalent, by interpola-

tion, to:

1000 +

$(1200-1000) \dfrac{[22.581 - 19.835]}{[23.497 - 19.835]}$

= 1150°C

28. Required gas temperature · 980°C · in example statement

29. Required Enthalpy of flue gas · Sufficient heat exists · 19, 20, 28

30. Net heat required · none · 29-26

31. Fuel excess air · -- · in example statement

32. Fuel required · none · Figure 4-3a, 30, 31

33. Air required for fuel · -- · Table 4-5, 31

34. Air required for fuel · -- · 33x32

35. Moisture from fuel · -- · Table 4-5, 31

36. Moisture generated · -- · 35x32

37. Dry gas from fuel · -- · Table 4-5, 31

38. Dry gas generated · -- · 37x32

39. Total dry gas flow · 13 526 kg/h · 38+20

40. Total moisture flow · 1166 kg/h · 36+19

41. Total heat at exit · 22 581 000 kJ/h · 26 + 32 x (fuel gross htg. value)

Table C.3-2

REFUSE INCINERATOR ANALYSIS

1.	Feed quantity (as received)	2083	Given
2.	Moisture fraction	.24	Given
3.	Moisture quantity (kg/h)	500	1 x 2
4.	Solids quantity (kg/h)	1583	1 - 3
5.	Noncombustible fraction	.145	Given
6.	Noncombustible quantity (kg/h)	230	4 x 5
7.	Combustible quantity (kg/h)	1353	4 - 6
8.	Heating value (kJ/kg combustible)	16 935	Given
9.	Total heat generated (kJ/h)	22 913 000	7 x 8
10.	Stoichiometric air ratio (kg/kg combustible)	5.1	Figure 4-2a
11.	Stoichiometric air (kg/h)	6900	7 x 10
12.	Excess air fraction	.85	Given
13.	Excess air (kg/h)	5865	11 x 12
14.	Total air required (kg/h)	12 765	11 + 13
15.	Moisture generated (kg/kg combustible)	.43	Figure 4-2b
16.	Moisture generated (kg/h)	582	7 x 15
17.	Humidity (kg/kg dry air)	.00657	Given
18.	Humidity (kg/h)	84	14 x 17
19.	Total moisture (kg/h)	1166	3 + 16 + 18
20.	Dry flue gas (kg/h)	13 536	7 + 14 - 16
21.	Radiation heat loss (kJ/h)	458 000	Given
22.	Ash heating value (kJ/kg)	250	Given
23.	Ash heat loss (kJ/h)	58 000	6 x 22
24.	Humidity Correction (kJ/h)	184 000	18 x 2186
25.	Miscellaneous heat loss (kJ/h)	0	Given
26.	Heat in flue gas (kJ/h)	22 581 000	9 - 21 + 24 - 25
27.	Flue gas temperature (°C)	1150	19, 20, 25
28.	Required gas temperature (°C)	980	Given
29.	Required flue gas heat content (kJ/h)	--	19, 20, 28
30.	Heat required (kJ/h)	--	29 - 26
31.	Fuel excess air	--	Given
32.	Fuel required (gal or m³/1)	--	Figures 4-3a, 30, 31
33.	Air for fuel (kg air/1 or m³)	--	Table 4-5, 31
34.	Air required (kg/h)	--	33 x 32
35.	Moisture from fuel (kg/1 or m³)	--	Table 4-5, 31
36.	Moisture generated (kg/h)	--	35 x 32
37.	Dry gas from fuel (kg/1 or m³)	--	Table 4-5, 31
38.	Dry gas generated (kg/h)	--	37 x 32
39.	Total dry gas flow (kg/h)	13 536	38 + 20
40.	Total moisture flow (kg/h)	1166	36 + 19
41.	Total heat at exit (kJ/h)	22 581 000	26 + 32 (fuel gross htg. value)

Example 3: Starved Air Incinerator

For the previous example, if the release were incinerated in
a starved air unit, consisting of two chambers, the total
gas flow and heat release from the system would be the same.
Conditions at the exit of the primary chamber could be
calculated as follows assuming 60% of the stoichiometric air
requirement was provided in the primary chamber:

The heating value of the combustible content would not
be fully realized in the primary chamber because only
60% of the stoichiometric air requirement is provided.
From Figure C.3-1, at 60% of stoichiometric, 72% of the
total heat capacity of the 16 935 combustibles is
released which is 0.72 x 16935 kJ/kg = 12 193 kJ/kg.
The air requirement is based on 16 935 kJ/kg while
moisture generation is based on 12 193 kJ/kg actual
heat release.

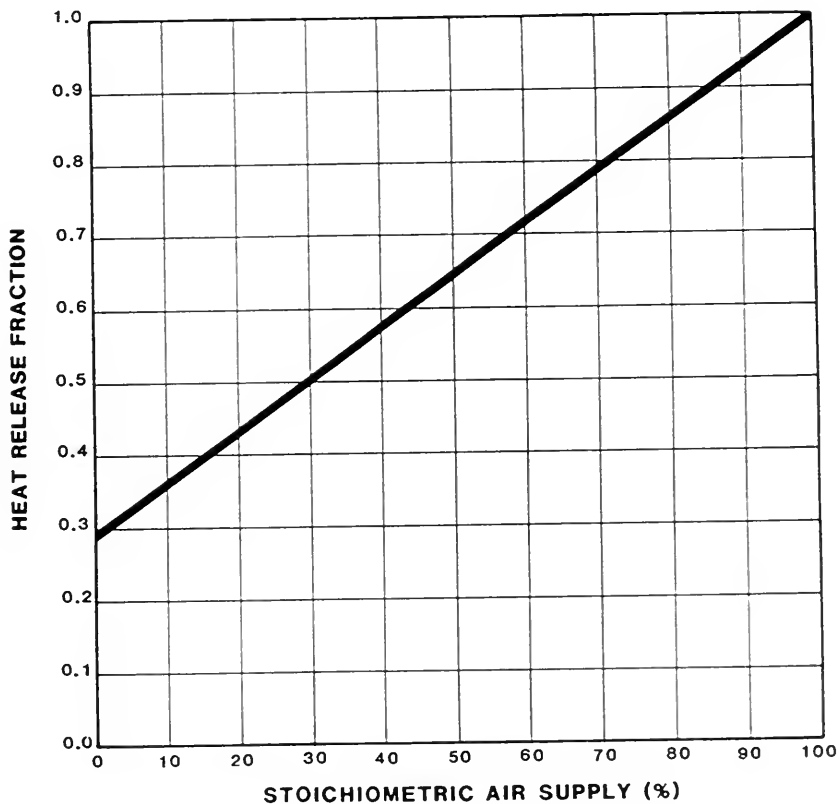Calculations follow and are summarized in Table C.3-3.

Figure C.3-1
HEAT RELEASE FRACTION vs STOICHIOMETRIC
AIR SUPPLY FOR STARVED AIR COMBUSTION

1. Feed rate   2083 kg/h   in example statement

2. Moisture fraction   .24   in example statement

3. Moisture quantity   2083 x .24 = 500 kg/h   (1x2)

4. Solids quantity   2083 - 500 = 1583 kg/h   (1-3)

5. Noncumbustible Fraction   0.11 ÷ (1-0.24) = 0.145   in example statement

6. Noncombustible quantity   1583 x .145 = 230 kg/h   (4x5)

7. Combustible quantity   1583 - 230 = 1353 kg/h   (4-6)

8. Heating value   12 913 kJ/kg   in example statement

9. Heat generated   1353 x 12 193 = 16 497 000 kJ/h (7x8)

10. Stoichiometric Air Ratio   5.1 kg air/kg combustible   From Fig. 4-2a

11. Stoichiometric Air   1353 x 5.1 = 6900 kg/h   (7 x 10)

12. Excess Air Fraction   .6 of stoichiometric   in example statement

13. Excess Air Required   6900 x .6 = 4140 kJ/h   (11x12)

14. Total Air Required   4140 kJ/h   (11+13)

15. Moisture generated   .32 kg water/kg combustible   from Figure 4-2b

16. Moisture generated   1353 x .32 = 433 kg/h   (7x15)

17. Humidity in air   .00657 kg water/kg air   from example statement

18. Humidity   4140 x .00657 = 27 kg/h   (14x17)

19. Total Moisture   500 + 433 + 27 = 960 kg/h   (3+16+18)

20. Dry flue gas   1353 + 4140 - 433 = 5060 kg/h   (7+14-16)

21. Radiant heat loss   .02 x 16 497 000 = 330 000 kJ/h 1%x(9)

22. Ash heat content   250 kJ/kg   in example statement

23. Ash heat loss	230 x 250 = 58 000 kJ/h	(6x22)
24. Humidity Correction	27 x 2186 = 59 000 kJ/h	(18)x2186
25. Miscellaneous heat loss	0	None
26. Heat in flue gas	16 497 000 - 330 000 - 58 000 + 59 000 - 0 = 16 168 000 kJ/h	(9-21-23+24-25)
27. Flue gas temperature	At 1200°C the enthalpy of air and moisture is 1300 and 5060 kJ/kg respectively. The heat content of this stream at 1200°C would be 1300 x 5060 + 5060 x 960 = 11.4 x 10^6 kJ/h which is lower than the heat in the flue gas, 16.168 x 10^6 kJ/h. The temperature exiting the primary chamber is, therefore, in excess of 1200°C.	
28. Required gas temperature	--°	in example statement
29. Required Enthalpy of flue gas	--	19, 20, 28

30. Net heat required	--	29-26

31. Fuel excess air	--	in example statement
32. Fuel required	--	Figure 4-3a, 30, 31
33. Air required for fuel	--	Table 4-5, 31
34. Air required for fuel	--	33x32
35. Moisture from fuel	--	Table 4-5, 31
36. Moisture generated	--	35x32
37. Dry gas from fuel	--	Table 4-5, 31
38. Dry gas generated	--	37x32
39. Total dry gas flow	5060	38+20
40. Total moisture flow	960	36+19
41. Total heat at exit	16 168 000	9 + 33 x (fuel gross htg. value)

Table C.3-3

STARVED AIR INCINERATOR ANALYSIS

1.	Feed quantity (as received)	2083	Given
2.	Moisture fraction	.24	Given
3.	Moisture quantity (kg/h)	500	1 x 2
4.	Solids quantity (kg/h)	1583	1 - 3
5.	Noncombustible fraction	.145	Given
6.	Noncombustible quantity (kg/h)	230	4 x 5
7.	Combustible quantity (kg/h)	1353	4 - 6
8.	Heating value (kJ/kg combustible)	12 193	Given
9.	Total heat generated (kJ/h)	16 497 000	7 x 8
10.	Stoichiometric air ratio (kg/kg combustible)	5.1	Figure 4-2a
11.	Stoichiometric air (kg/h)	6900	7 x 10
12.	Excess air fraction	.6*	Given
13.	Excess air (kg/h)	4140	11 x 12
14.	Total air required (kg/h)	4140	11 + 13
15.	Moisture generated (kg/kg combustible)	.32	Figure 4-2b
16.	Moisture generated (kg/h)	433	7 x 15
17.	Humidity (kg/kg dry air)	.00657	Given
18.	Humidity (kg/h)	27	14 x 17
19.	Total moisture (kg/h)	960	3 + 16 + 18
20.	Dry flue gas (kg/h)	5060	7 + 14 - 16
21.	Radiation heat loss (kJ/h)	330 000	Given
22.	Ash heating value (kJ/kg)	250	Given
23.	Ash heat loss (kJ/h)	58 000	6 x 22
24.	Humidity Correction (KJ/h)	59 000	18 x 2186
25.	Miscellaneous heat loss (kJ/h)	0	Given
26.	Heat in flue gas (kJ/h)	16 168 000	9 - 21 - 23 + 24 - 25
27.	Flue gas temperature (°C)	over 1200	19, 20, 25
28.	Required gas temperature (°C)	--	Given
29.	Required flue gas heat content (kJ/h)	--	19, 20, 28
30.	Heat required (kJ/h)	--	29 - 26
31.	Fuel excess air	--	Table 4-7
32.	Fuel required (gal or m³/h)	--	Figure 4-4, 4-5 29, 31
33.	Air for fuel (kg air/l or m³)	--	Table 4-5, 31
34.	Air required (kg/h)	--	33 x 32
35.	Moisture from fuel (kg/l or m³)	--	Table 4-7, 31
36.	Moisture generated (kg/h)	--	35 x 32
37.	Dry gas from fuel (kg/l or m³)	--	Table 4-7, 30
38.	Dry gas generated (kg/h)	--	37 x 32
39.	Total dry gas flow (kg/h)	5060	38 + 20
40.	Total moisture flow (kg/h)	960	36 + 19
41.	Total heat at exit (kJ/h)	16 168 000	26 + 32 x (fuel gross htg. value)

*Fraction of stoichiometric